BMP Pilot Study

Guidance Manual

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Chapter 1 Introduction

The California Department of Transportation (Caltrans) Statewide National Pollutant Discharge Elimination System (NPDES) Permit regulates stormwater and construction activities on Caltrans properties. It requires that stormwater discharges meet water quality standards through implementation of appropriate temporary and permanent Best Management Practices (BMPs) and other measures. Examples of BMPs include preserving existing vegetation, slope/surface protection systems, biofiltration strips and swales, and detention basins. The Statewide NPDES Permit stipulates that treatment BMPs must be implemented to the Maximum Extent Practicable (MEP) and construction BMPs must meet Best Conventional Technology/Best Available Technology (BCT/BAT) requirements.

As required by the Caltrans Statewide NPDES Permit, a final Stormwater Management Plan (SWMP) was approved by the State Water Resources Control Board (SWRCB) on May 17, 2001. The SWMP includes a list of BMPs that have been evaluated and selected for use on Caltrans properties, facilities, and activities. It also discusses the process used to select appropriate BMPs based on water quality requirements and pollutants of concern for specific water bodies, and also considers site constraints. Generally, only BMPs that have been approved as described in the SWMP are incorporated into projects. If project conditions prohibit the use of approved BMPs, Caltrans has the option of proposing the incorporation of a non-approved BMP as a pilot project. The purpose of a pilot project is to evaluate the feasibility of a particular pilot technology, with further deployment being dependent upon the outcome of the study.

1.1 Caltrans Intent Regarding BMP Evaluation

It is Caltrans' intent to develop a "toolbox" of BMPs from which a Project Engineer or Resident Engineer can select those that best meet the MEP and BCT/BAT requirements for a specific site. It is important for Caltrans to obtain information regarding the performance, cost, installation, and maintenance requirements of BMPs. This information can be used to enhance the stormwater program, assess the effectiveness of the SWMP, and establish the need for new or improved BMPs. The evaluation of BMPs helps in the development of models and compilation of key data necessary to make stormwater quality decisions. It is Caltrans' intent to evaluate BMPs appropriate for its projects and operations using well-conducted and scientifically-sound pilot studies.

1.2 Purpose of Conducting Pilot Studies

Before approving BMPs for general deployment, Caltrans requires information on the performance capabilities, technical feasibility, maintenance requirements, and life cycle[1] costs for the BMPs. To obtain this information, well-designed and carefully monitored pilot studies are conducted to test components of the BMP or the BMP itself before full-scale deployment. This approach is recommended as a method to achieve cost and time savings while meeting regulatory requirements to address stormwater quality impacts. Pilot studies are also used to test refinements and improvements in BMPs.

Purposes of conducting pilot studies include the following:

- Evaluate the constituent removal efficiency and general performance of the BMP;
- Allow comparison of the performances of different BMPs;
- Predict the water quality downstream of a BMP (effluent quality);
- Determine the costs of the BMP, including capital, operation, and maintenance costs; and
- Determine design guidelines for BMPs.

Data obtained from a pilot study can be compared to other test data by researching existing databases such as the Caltrans Stormwater Information System (SWIS) and the International Stormwater BMP Database, which was developed by the American Society of Civil Engineers (ASCE).

1.3 Purpose of this Guidance Manual

This BMP Pilot Study Guidance Manual (Manual) presents guidance for a Project Delivery Team (PDT) (e.g., Caltrans management, staff, and/or engineering consultants and academia) to use in planning, performing, evaluating, and reporting BMP pilot studies. The Caltrans Comprehensive Monitoring Protocols Guidance Manual (Caltrans 2003a) is a companion manual and should be closely consulted when conducting a pilot study. Every pilot study that involves construction under a contract and/or within the Caltrans right-of-way shall have a District NPDES Coordinator appointed to the PDT. Typical BMPs discussed in this Manual include temporary construction BMPs, maintenance BMPs, and source control and treatment BMPs, such as preserving existing vegetation, slope/surface protection systems, biofiltration strips and swales, and detention basins. This Manual is intended to be used in conjunction with existing

[1] Life cycle costs include original construction, regular and irregular maintenance, and major rehabilitation or re-construction decommissioning at the end of the design life.

Caltrans guidance manuals and protocols for stormwater monitoring, BMP design and implementation, and water quality monitoring.

Adherence to this Manual will provide consistency in planning, executing, and controlling monitoring, scoping, development, deployment, and data reporting methods among Caltrans pilot projects. Data obtained from the pilot study shall be submitted in the Caltrans format specified in this Manual, so that it can be directly managed by SWIS, which will also be compatible with the International Stormwater BMP Database. The advantages of using consistent procedures for all BMP pilot studies include:

- More efficient execution of BMP studies (i.e., less re-inventing of the wheel);
- Fewer mistakes in experimental design;
- Better agreement on the interpretation of results;
- Easier sharing of information and data;
- Increased confidence in approving appropriate BMPs for implementation; and
- Implementing lessons learned from past efforts.

This Manual also contains procedures specific to BMP pilot studies that are used to augment Caltrans Project Development Procedures. For example, Chapter 2 of this Manual makes use of concepts from the U.S. Environmental Protection Agency Data Quality Objective (DQO) process. The DQO process is an efficient and effective procedure used to systematically plan a pilot study, collect and evaluate the resulting data, and draw common sense transparent conclusions. This process can either be used to establish "performance" criteria for newly acquired data, or to establish acceptance criteria for previously gathered data.

This Manual is not a compilation of mandatory standards. The procedures established within this Manual are for informational purposes only and can be used as a guidance tool for Caltrans employees, contractors, and academia. The prudent practices provided herein are subject to amendment at any time, whenever more technical knowledge and specific experience about a condition is acquired. Moreover, this Manual is not intended to be used as a textbook or a substitute for engineering judgment, technical knowledge, or overriding Department policies and procedures. If a conflict between this Manual and other Caltrans guidelines exists, consult the Department Contract Manager or the Department Task Manager.

1.4 District Coordination

Successful pilot studies require the participation and engagement of many individuals and groups. The HQ Department of Environmental Analysis' coordination with the District NPDES

Coordinator is essential for each pilot. The District NPDES Coordinator must be involved during the planning of projects through reporting. The degree of involvement will vary from project-to-project and by District. The District NPDES Coordinator will enroll other functions (such as Hydraulics, Environmental, and Office Engineer) that will most likely be needed at various stages of pilot study execution. The District NPDES Coordinator should be involved during the resolution of local project issues, and be kept informed throughout the life of the project. A summary of where coordination with District functions might be appropriate is presented in Table 1.1.

Table 1.1 District Function Coordination Requirements

Function	Project Planning	Site Selection	Project Approval	Project Design	Construction/ Construction Management	Operation, Maintenance & Monitoring
CADD				✓		
Construction	✓		✓	✓	✓	
Environmental	✓	✓	✓	✓	✓	✓
Geotechnical	✓		✓	✓		
Hydraulics	✓		✓	✓		
Landscape	✓		✓	✓		
Maintenance	✓		✓	✓		✓
Materials	✓		✓	✓		
NPDES	✓	✓	✓	✓	✓	✓
Office Engineer				✓		
Quality Control	✓		✓	✓		
Right-of-Way	✓		✓	✓		
Safety				✓		
Structures				✓		
Traffic Operations	✓		✓	✓		

Note that the requirements presented in the above table are recommendations, and that coordination with additional functional units may be necessary. Clarification or verification on the need for District coordination can be confirmed with the Department Task Manager.

1.5 How to Use this Manual

This Manual is organized into eight major components with supporting appendices:

- Chapter 1, Introduction: provides background information and presents the purpose of this Manual.
- Chapter 2, Project Planning: describes the process to plan the applied component of the study.

- Chapter 3, Project Site Selection: describes the procedures for selecting sites to conduct the pilot study.
- Chapter 4, Permits and Environmental Clearance: presents environmental and permitting requirements with which pilot studies need to comply.
- Chapter 5, Project Design: describes the processes through which plans, specifications, and cost estimates are prepared.
- Chapter 6, Project Construction: presents guidelines for the construction or installation of the pilot BMP.
- Chapter 7, Operation, Maintenance, and Monitoring: includes guidance for the preparation and implementation of an Operation, Maintenance, and Monitoring (OM&M) Plan.
- Chapter 8, Interim and Final Reports: describes how pilot study results will be reported; presents guidance on data analyses, interpretation of findings, and format and content for Interim and Final Reports.
- Appendices provide annotated outlines for deliverables.

The guidelines presented in Chapters 2, 4, 5, and 6 of this Manual assume that any pilot construction/installation activities are accomplished using one or more Architectural-Engineering Services Contracts (A-E Contracts), which is the most common delivery method. This includes the scenario in which the design and construction are performed by the same A-E Consultant, and the scenario in which the design and construction are performed by different A-E Consultants. No distinction is made between these two scenarios in the above-mentioned chapters as they require similar levels of effort and detail. Appendix A should be consulted for additional requirements for other delivery methods. The actual delivery method may vary from one pilot study to another, and it is the responsibility of the Department Task Manager to receive approval for the delivery method to be implemented.

The approach described herein has been developed to fit within the appropriate Work Breakdown Structure (WBS) codes and activities identified in the Caltrans Project Development Procedures Manual (PDPM) (updated March 2006) and the Guide to Project Delivery Workplan Standards, Release 8.0A. These documents can be found on the web at the following sites:

- http://www.dot.ca.gov/hq/oppd/pdpm/pdpmn.htm
- http://www.dot.ca.gov/hq/projmgmt/documents/wsg/workplan_standards_guide_8.0a.doc

WBS codes are referenced in this Manual where relevant. Table 1.2 provides a listing of WBS codes associated with elements of this Manual.

Table 1.2 Work Breakdown Structure (WBS) Codes

WBS Code	Description
150	Project Initiation Document (PID)
150.05	Study Plan
150.05.05	Review Background Information
150.05.35	Describe the Problem
150.15	Optimize and Validate the Study Plan
150.20	Preliminary Environmental Assessment Report
150.25.25	Storm Water Data Report
180.10	Environmental Clearance
185.05	Data Review
185.20	Field Investigations
205.05	Engineering and Detailed Design
230	Permits
270	PS&E Production
270.20	Construction and Installation
	Water Pollution Control
	Hazardous Waste Management
	Submittals, Requests for Information, and Requests for Clarification
270.30	Progress Documentation
295	Post Construction
295.15	As-Builts
295.25	Construction Report
295.35	Certificate of Environmental Compliance

Figure 1-1 presents the components of this Manual. Chapter references are provided in the flowchart to facilitate cross-referencing. Where appropriate, flow charts, diagrams, and examples have been included in this Manual for reference. Additionally, key factors and lessons learned are highlighted throughout this Manual. Figure 1-2 shows a typical Pilot Study Process Flowchart. Each associated section within this Manual, as applicable, is referenced in the flowchart.

Where appropriate, this Manual references other applicable Caltrans policies, manuals, and guidance. This Manual's purpose is to supplement and further define pilot BMP implementation and not replace other Caltrans manuals. The level of detail contained in this Manual may differ from the other referenced documents. Accordingly, it is recommended that the PDT make best use of the guidance contained in this Manual and that which is cross-referenced in other documents.

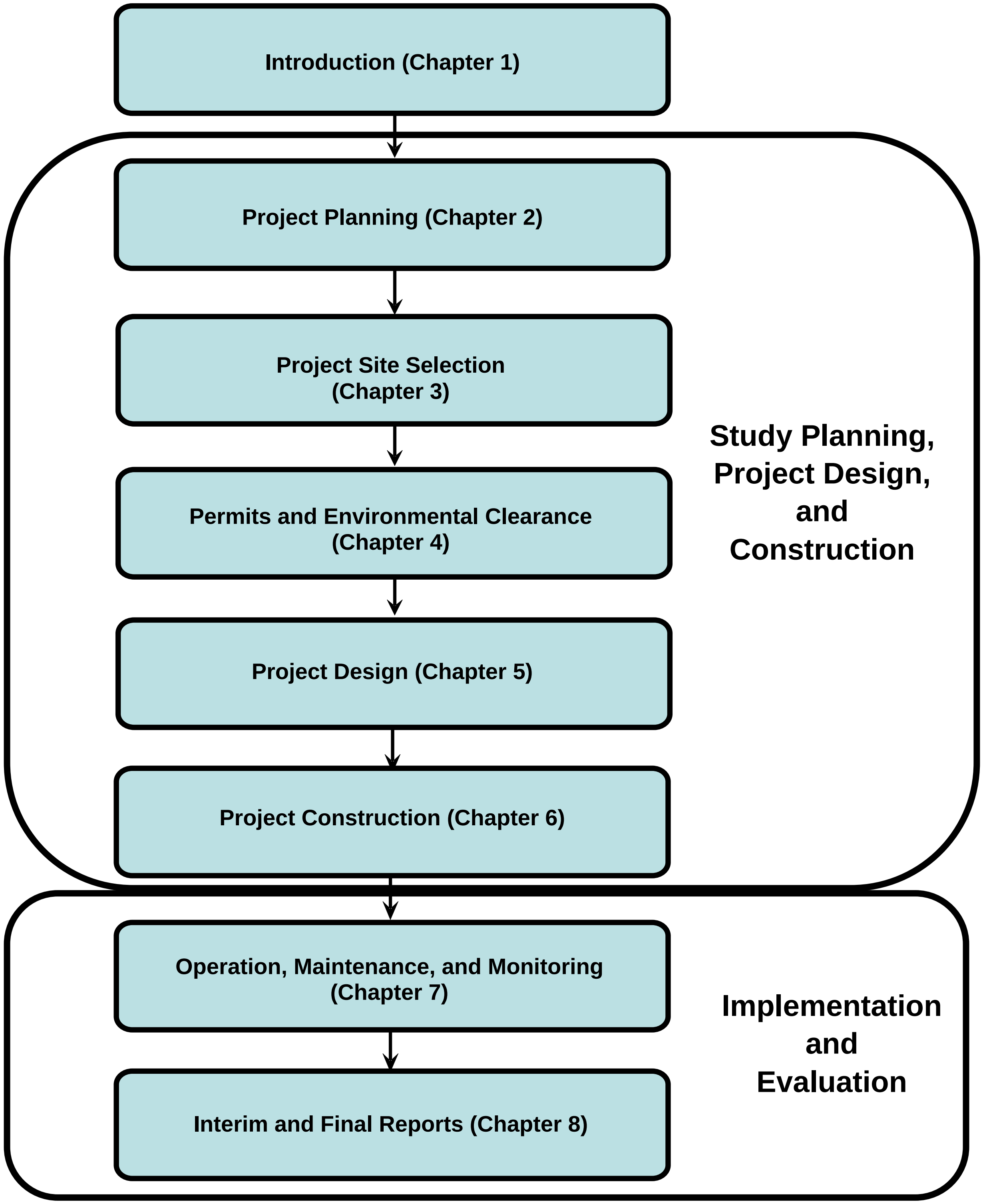

Figure 1-1 Guidance Manual Contents

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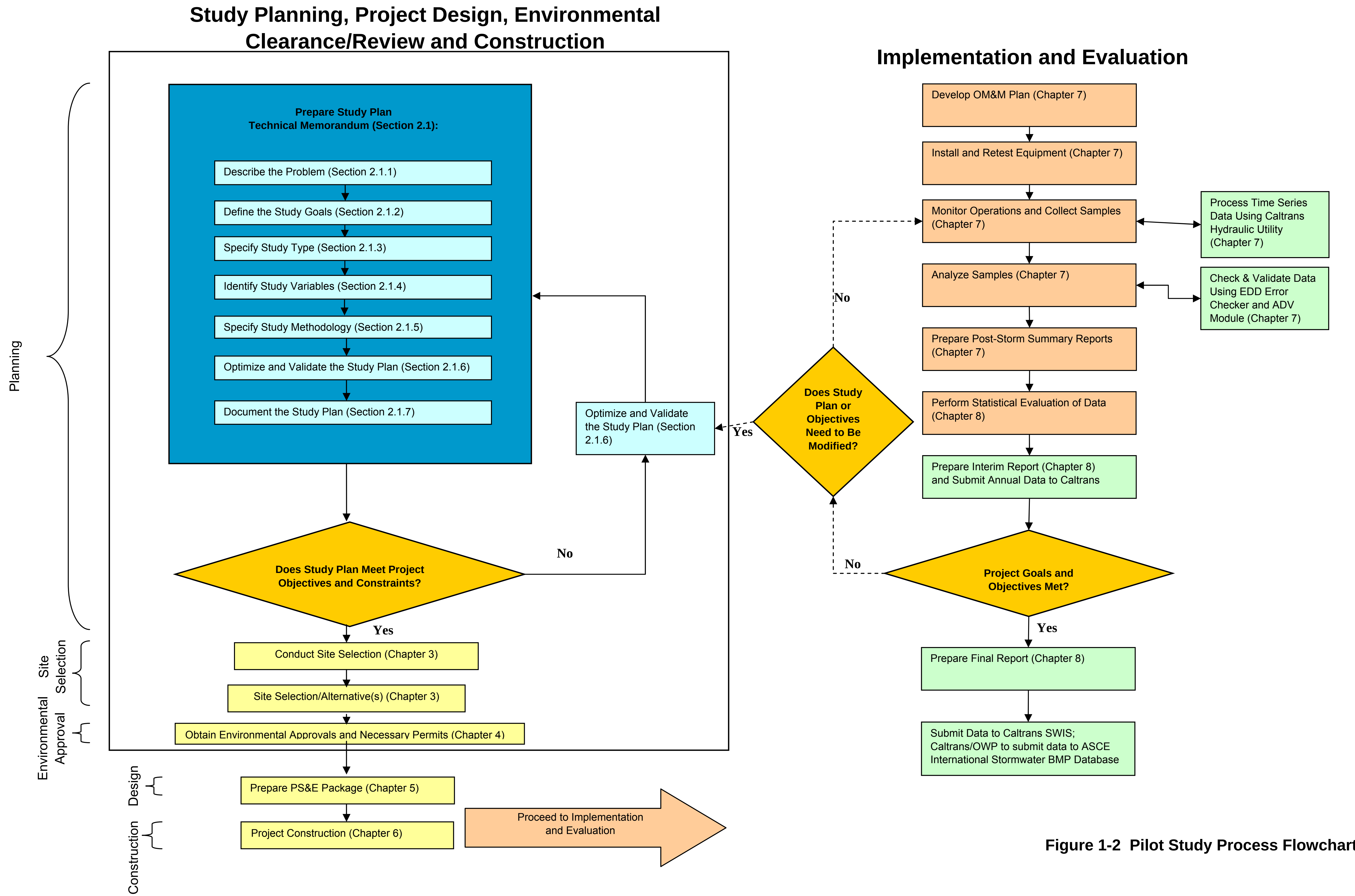

Figure 1-2 Pilot Study Process Flowchart

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1.6 Task Order Development Process

When one or more pilot study activities are performed by a Consultant under an A-E Services Contract, specific task orders are issued to the Consultant identifying the work to be performed, appropriate project deliverables, the project schedule, and the project budget. The process of developing and issuing task orders is as follows:

1. Caltrans initiates a Scope of Work, obtains internal approval, prepares a draft task order, and sends draft task order to Consultant.
2. Consultant reviews and confirms Scope of Work and project schedule, requests clarification when needed, and prepares draft budget for Caltrans review.
3. Caltrans reviews draft budget and works with Consultant to reach an agreement on final budget.
4. Consultant finalizes task order (incorporating final budget and other agreed upon revisions), and sends two signed copies to Caltrans.
5. Caltrans obtains task order approval and necessary signatures.
6. Caltrans issues Notice to Proceed and Consultant begins work.

1.7 Other Resources

The technical literature contains several documents and websites describing considerations and procedures for designing, constructing, and implementing pilot studies to evaluate BMP performance. This Manual builds on information available in those resources by providing evaluation procedures and report guidelines that are specific to Caltrans pilot studies. Relevant documents of particular value are listed below.

- ASCE. 2002. Urban Stormwater BMP Performance Monitoring. EPA/821/B-02/001. U.S. Environmental Protection Agency, Office of Water.
- ASCE/USEPA. 1999. Development of Performance Measures, Task 3.1 – Technical Memorandum (TM), Determining Urban Stormwater BMP Removal Efficiencies. U.S. Environmental Protection Agency, Office of Water.
- California Department of Transportation. 2003. Comprehensive Monitoring Protocols Guidance Manual: Stormwater Quality Monitoring Protocols, Particle/Sediment Monitoring Protocols, Gross Solids Monitoring Protocols, Toxicity Monitoring Protocols, and Caltrans Data Reporting Protocols.
- United States Environmental Protection Agency. 2006. Guidance on Systematic Planning Using the DQO Process. EPA/240/B-06/001. February 2006.

Relevant websites that are of particular value include:

- Caltrans Division of Environmental Analysis: http://www.dot.ca.gov/hq/env
- Caltrans Standard Environmental Reference: http://www.dot.ca.gov/ser/
- United States Environmental Protection Agency: http://www.epa.gov/
- American Society of Civil Engineers: http://www.asce.org/asce.cfm/

Chapter 2 Project Planning

Project planning includes two distinct activities: (1) planning the applied component of the pilot study; and (2) project initiation (i.e., pre-programming phase of project development) of the pilot study. This chapter focuses on planning the applied component, which results in a Study Plan Technical Memorandum (TM). Appendix J focuses on the project initiation process, which results in the Project Initiation Document (PID).

2.1 Study Plan, WBS 150.05

Developing the Study Plan is the most critical step in any investigation. A poorly-planned study can easily lead to erroneous conclusions and poor management decisions, resulting in misdirected or wasted time and resources.

Basic questions to consider during the development of the study include:

- What are the study goals and objectives?
- What experimental variables will be studied?
- What variables need to be controlled and how will this be done?
- How much and what kinds of data are needed to meet the study objectives?
- How will the data be collected, reported, and interpreted?
- Can the study be accomplished within applicable resource constraints?

The types of studies primarily addressed in this chapter are those intended to assess the performance and/or costs of BMPs in field scale applications. Such studies aim at proving or improving the beneficial effects of management activities or treatment devices. Nevertheless, other types of studies such as monitoring efforts to characterize discharges, and laboratory or small-scale experiments, also benefit from the creation of study plans. Describing problems, defining study goals, identifying important study parameters, specifying methodologies, and validating and optimizing plans are all essential components of any good experiment. The planning steps described in this chapter should be considered in the creation of study plans for monitoring and small-scale experiments. Not every step will be appropriate, however, and the resulting document will most likely be smaller than that envisioned here. The exact scope should be coordinated with the Department Task Manager.

The components of the study planning process are shown in the flowchart presented in Figure 2-1. Section references are provided to facilitate cross-referencing. Each of these components are discussed in detail below. Appendix B provides an outline of the Study Plan TM that must be prepared to document the planning phase of the study.

It is important to initiate Study Plan development with key experts so the Study Plan can be developed in a way that is comprehensive to the needs of the study. For example, for the Erosion Control Pilot Study, experts in the fields of botany, erosion and sediment control, erosion prediction modeling, and statistics participated during initial discussions to help foster ideas to create the design of the Study Plan TM. These discussions should also reflect any other information contained in the Stormwater Research Strategic Plan.

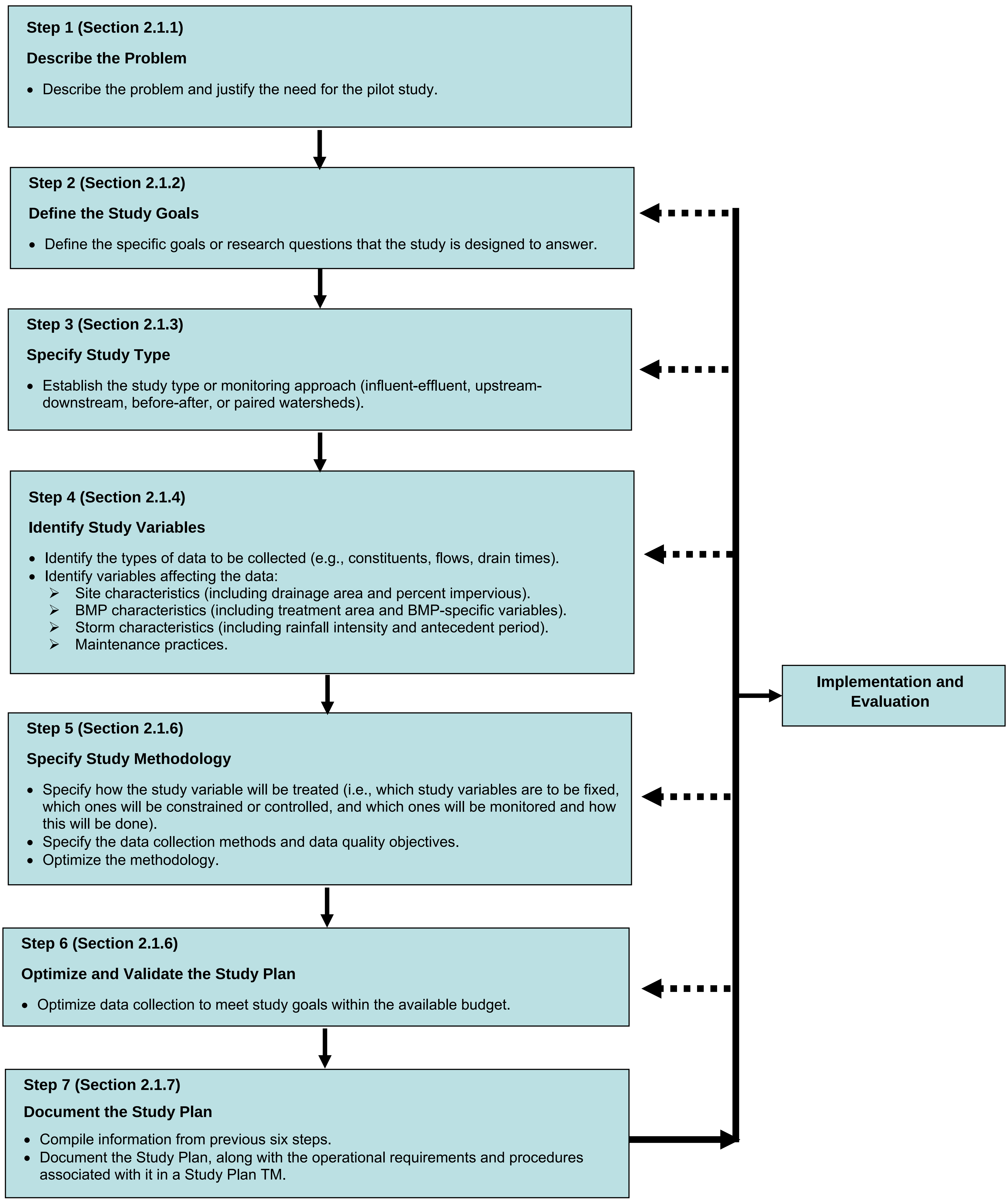

Figure 2-1 Study Plan Technical Memorandum Process Flowchart

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2.1.1 Step 1: Describe the Problem, WBS 150.05.35

In this step, the problem or need that requires new data is described. This is done so that the focus of the study and how its results will address the problem will be clear and unambiguous and tied to Departmental needs.

In general, BMPs are evaluated with respect to (1) technical feasibility, (2) operation and maintenance requirements, (3) performance, and (4) costs of implementation. Technical feasibility hinges on whether a BMP can function under the conditions encountered at Department roadways and facilities, and whether it can comply with Department drainage and safety requirements. A BMP must be designed and constructed so it can be effectively operated and safely maintained by Department personnel throughout its intended life. Maintenance requirements must be well understood and defined with respect to scope and frequency. With regards to pollutant removal performance, treatment BMPs should generally demonstrate pollutant removal effectiveness equal to or greater than those of currently-approved BMPs. Finally, pollution control benefits must have a reasonable relationship to the costs of implementing the BMP. Detailed criteria relating to these four issues are presented in the SWMP.

Caltrans' other needs are described in the SWMP, various "needs assessments," and the Stormwater Research Strategic Plan. Some of Caltrans' needs arise from its legal obligations under the terms of the Statewide NPDES Permit. Other needs are internally generated and generally have to do with improving BMP reliability or practicality, or minimizing costs. Typical problems that may warrant a BMP pilot study include:

- Determining the performance, costs, and limitations of a BMP for the purpose of approving it for general use;
- Measuring BMP performance to determine its ability to meet specific water quality standards such as Total Maximum Daily Load (TMDL) waste allocations;
- Optimizing design parameters or maintenance practices; and/or
- Determining BMP benefits for receiving waters.

In addition to describing the need, the problem statement should describe how the pilot study will help Caltrans address the problem.

Writing the problem statement for the Study Plan is an opportunity to check the justification for the study. If the PDT encounters serious questions as to whether the BMP proposed for testing will be effective, feasible, or legal, it should communicate this to the Project Manager so that the Department can decide whether to continue, modify, or stop the proposed pilot study.

Examples from the Files ....

Usefulness of a Problem Description

Explicitly stating the overall problem is a good way to make sure research stays on track since specific study questions may not look similar. In the Tahoe Small Scale Studies, for instance, the overall problem was meeting the legally-mandated effluent limits in the Tahoe Basin. To meet this requirement, Caltrans conducted a series of small-scale pilot tests of new concepts and ideas. The overall objective of these studies was to develop new BMPs that are able to meet the regulatory limits.

Over several years a number of studies were carried out with a variety of specific study questions, such as:

- What are the effluent characteristics of an Austin sand filter?
- Should flow through media filters be controlled with an orifice?
- Can a media filter treat one year's worth of runoff without clogging?
- How reliably does chemical coagulation treat runoff?
- Are chemical coagulants toxic in the standard EPA three-species test?

Often several studies may be needed to solve the overall problem. Consequently, research questions for specific studies are relatively narrow and meant to produce measurable answers that address some small aspect of the overall problem.

Examples from the Files ....

Problem Definition for the Ornamental Roadside Vegetated Treatment Sites Study

Caltrans has historically included vegetated landscape in highway design and construction. Many of these landscaped areas have the potential to function similarly to engineered biofiltration systems such as biostrips and bioswales. The potential benefit of these vegetated systems needs to be documented to determine if Caltrans can obtain treatment credit from the RWQCBs for biofiltration. Therefore, Caltrans has initiated the Ornamental Roadside Vegetated Treatment Sites Study to investigate the effectiveness of existing landscapes within the ROW where groundcover and low-growing shrub vegetation may be providing treatment of highway runoff that is functionally equivalent to biostrips and bioswales specifically designed for water quality treatment.

2.1.1.1 Review Background Information, WBS 150.05.05

In most cases, the decision to proceed with the pilot study will have already been made, based on previous work sponsored by Caltrans or others. Ideas for BMP studies can come from many sources, and usually there is a “paper trail” that leads to the decision to undertake the study at hand. As needed and appropriate, the PDT should examine literature reviews, reconnaissance studies, laboratory studies, technical memoranda, or other documents that support the inclusion of the BMP in a Stormwater Research Strategic Plan. Conducting a background review may also identify that one or more of the specific study questions have already been answered by others who have tested the same BMP. Other sources of information include technical journals, trade publications, reference manuals, vendor information, and case studies. The PDT shall consult with Caltrans to determine the appropriate level of effort needed for the background review.

2.1.2 Step 2: Define the Study Goals

The next step in the development of a Study Plan is to define the specific goals of the project. Typically, this is done by formulating study questions that the pilot study will be designed to answer. The questions must be designed to elicit the information needed to solve the problem or fill the data need. They must also be specific enough to provide the basis for a detailed Study Plan.

In some cases, the study questions may have already been formulated in a document such as a Stormwater Research Strategic Plan, a District request, or an agreement with a Regional Board. These should be reviewed to assure that they are sufficiently specific and revised if they are not.

2.1.2.1 Describe BMP Processes

To be able to write specific study questions, it is necessary to know how the BMP works. This knowledge is the basis for hypotheses that guide the formulation of study questions. For example, if the need is to improve the performance of detention basins, then the knowledge that detention basins work by sedimentation leads to a study question about the relationship between detention time and pollutant removal. Treatment or *unit* processes in BMPs may include sedimentation, filtration, biofiltration, infiltration, adsorption, coagulation, and flocculation. For each unit process identified, key factors and variables known to affect the treatment and operation of the unit process should be identified. For instance, key factors and variables that affect media filtration include influent characteristics (e.g., hydraulic loading rate, efficiency of pretreatment), media properties (type, grain size, uniformity coefficient, and media depth), number of years in operation, and maintenance practices (e.g., degree of sediment accumulation, frequency of removing sediment from the surface). Information on the factors and variables affecting treatment effectiveness and operation of unit processes can be found in the literature on standard water and wastewater treatment processes, and in the growing body of literature on the use of natural systems (e.g., overland flow, wetlands, infiltration) to treat water. It is important to focus on the key factors and variables so that they can be given proper consideration in the Study Plan.

A description of the BMP should be provided in the Study Plan with a schematic of the BMP system that shows influent, effluent, and bypass/overflow locations and the dominant unit processes. An example schematic is shown in Figure 2-2.

Examples from the Files ....

BMP Description for Biofiltration Strips

Biofiltration strips are broad vegetated surfaces over which runoff flows in relatively thin sheets. The objective of the Roadside Vegetated Treatment Site (RVTS) Study was to determine if standard roadway design requirements result in vegetated buffer strips with treatment capabilities equivalent to biofiltration strips specifically engineered for water treatment. RVTS function by allowing runoff to slowly pass through the vegetation, thereby filtering pollutants from the runoff. RVTS also infiltrate runoff and reduce flow volume. Biofiltration strips remove pollutants by filtration, infiltration, adsorption and ion exchange, and biological degradation or assimilation. Consequently, the study variables included length, slope, vegetation density, and hydraulic

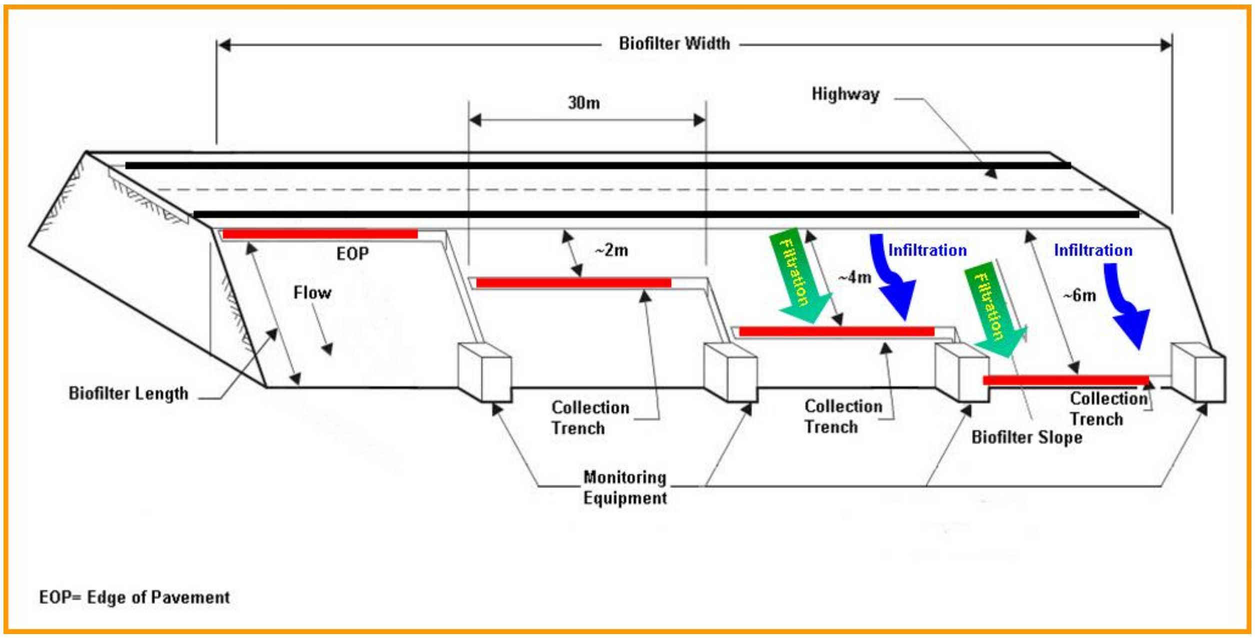


Figure 2-2 Example Schematic - Roadside Vegetated Treatment Site

2.1.2.2 Formulate Study Questions

In planning studies of BMP performance, it is helpful to look at the goals of the study in terms of the questions that need to be answered in the evaluation. Study questions usually reflect an underlying conceptual understanding of how the study subject works. BMP study questions, for instance, may reflect past knowledge and also assumptions about treatment mechanisms, the nature of the pollutants entering the BMP, or how hydrologic characteristics affect performance. Of particular interest are key assumptions that have the potential to influence the study. In developing study questions, such underlying assumptions should be examined. The possibility that these assumptions prove to be untrue should be considered part of the alternative outcomes analysis. BMP studies are usually conducted to obtain information regarding one or more of the following study questions:

Approval Questions

Approval questions are of immediate importance to Caltrans for determining whether a BMP is appropriate for widespread deployment. Answers to questions like the ones listed below (the list may not be exhaustive) are needed before a BMP can be approved.

- What degree of treatment does the BMP provide under typical operating conditions?
- How does effectiveness vary for various pollutants of concern?
- How does the BMP’s performance compare to other approved BMPs?
- What are the operation and maintenance requirements?
- What are the life cycle costs (labor and materials) associated with the installation, operation, and maintenance of the BMP?
- Does the BMP protect or degrade downstream beneficial uses?
- Does the BMP have vector control issues?

Optimization Questions

Optimization questions are intended to provide greater insight into the effects of various process variables on BMP performance. Some process variables are affected by design elements (e.g., basin volume); some are affected by operational practices (e.g., filter scraping); and some are affected by site and climate conditions. Answers to optimization questions can lead to future improvements in design or deployment. Some example optimization questions include:

- How do design or site variables (e.g., area of filter fabric, length of infiltration trench, etc.) affect performance?
- How does performance vary with influent concentrations or loads?
- How does performance vary with different operational and/or maintenance activities?

- How does performance vary with storm characteristics such as rainfall amount, rainfall intensity, and antecedent weather conditions?
- Does effectiveness improve, decrease, or remain unchanged over time?

The ability of a BMP pilot study to answer these questions is a vital component of the planning stages of the study. Further discussion of treatment effectiveness, life cycle costs, and BMP comparisons follows.

Treatment Effectiveness

The treatment effectiveness of a BMP can be measured in terms of the effluent water quality, or the pollutant removal efficiency in terms of concentration or load. Because in different regulatory settings each may be important, the data needed to calculate all three parameters (i.e., effluent concentration, concentration reduction, and load reduction) should be collected during the pilot study. Often, the variability of effluent quality as a function of differing influent concentrations, flows, or environmental conditions (e.g., temperature) is of interest. One aspect of characterizing effluent quality is the maximum degree of treatment that can be achieved by the BMP. In some types of BMPs the effluent water quality for some constituents may approach a practical lower limit called an “irreducible concentration.” This concentration is the lowest effluent concentration for a given parameter that can be achieved by a specific type of stormwater management practice. The irreducible concentration is determined by the chemical and physical nature of the pollutant of concern and the treatment mechanisms and processes within the BMP. For further discussion, refer to Section 2.9.2.2 of the ASCE Urban Stormwater BMP Performance Monitoring Manual (ASCE 2002).

Life Cycle Costs

In addition to investigating the treatment effectiveness of a BMP, it is important to obtain cost information so that the life cycle cost can be calculated. The life cycle cost of a BMP includes initial construction plus the present worth of the annual maintenance and future rehabilitation. Determining accurate costs for a BMP helps define long-term investment requirements and allows Caltrans to make more cost-effective decisions when approving BMPs. Refer to Section 7.4.5 of this Manual for guidance on procedures to track costs during the Operation, Maintenance, and Monitoring phase of the pilot study.

BMP Comparisons

How a BMP's performance compares with that of other BMPs is a key question related to approval and implementation priority. Example comparisons include: (1) the ability to meet effluent quality goals; (2) cost effectiveness; and (3) size, appearance, and ease of maintenance.

Data obtained from a pilot study can be compared to other test data by researching existing databases such as the Caltrans SWIS and the International Stormwater BMP Database. In some cases, it may be appropriate to include multiple BMPs or variants on BMPs in the proposed study.

At the end of this chapter is a checklist (Table 2.2) that can be used to validate the proposed study in relation to the problem and other Caltrans needs.

2.1.3 Step 3: Specify Study Type

In conducting a BMP study, several different monitoring approaches (study types) can be chosen. The selection is based on the study questions, the type of BMP, the study constraints, and the current and historic conditions of the study area. Each type of study has associated strengths and weaknesses as described below.

2.1.3.1 Influent–Effluent Approach (In-and-Out)

Comparison of influent and effluent water quality is the method most often used in studies of treatment BMPs. This method is used to estimate the pollutant removal capability of an individual BMP or a series of in-line BMPs (i.e., a treatment train). The typical monitoring layout strategy for the influent-effluent approach is illustrated in Figure 2-3. The monitoring layout for a treatment train would look similar to Figure 2-3, except that the effluent from the first unit process also serves as the influent to the second unit process in the series. Typically, the effluents from both unit processes would need to be monitored.

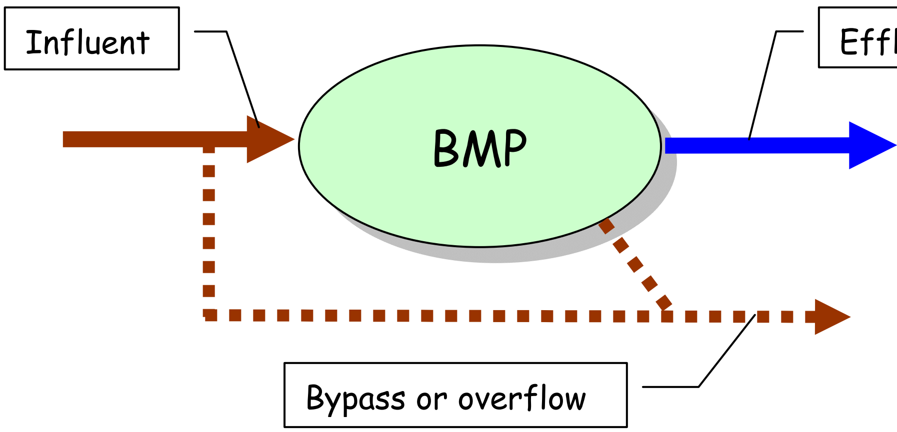


Figure 2-3 Influent–Effluent Approach Showing Monitoring Locations

There are several benefits in applying the influent-effluent approach for BMP efficiency:

- Environmental factors are better controlled in this approach and statistical variability in the data is generally less.
- The cost of monitoring is substantially less than that of watershed approaches (discussed below) because fewer data points are needed.
- The time required for monitoring can be substantially less than that required for watershed approaches because a calibration period prior to a monitoring program is not required.
- If climate is not a major factor affecting performance, the experimental results for a particular type of BMP can be extrapolated to other physiographic regions.[2]

> *Examples from the Files ....*
>
> **Influent-Effluent Example**
>
> The influent-effluent approach was used widely in the Retrofit Pilot Study conducted in Los Angeles and San Diego. In this study, influent and effluent sampling was performed on sand filters, biofiltration strips and swales, dry and wet detention basins, and oil-water separators. This approach works best when there is a discrete inflow and outflow from a treatment system. Where the flows are not easily accessed, such as in infiltration facilities or drain inlet inserts, alternative approaches must be used.

A limitation to the influent-effluent approach is that downstream benefits of BMP implementation cannot be established without additional data collection. Influent-effluent studies reveal pollutant removal rates and effluent flows and concentrations, but do not directly measure a BMP's effects on aquatic or riparian communities. Similarly, hydromodification

[2] Physiographic regions are regions defined based on landform characteristics.

impacts (i.e., increased erosion of channel beds and banks, sediment pollutant generation, or other impacts due to increased erosive forces) can be inferred, but are not directly measured.

2.1.3.2 Watershed Approaches

Watershed approaches to BMP evaluation are used where (1) discrete inflows and outflows cannot be monitored, (2) the BMPs are of a dispersed nature such as porous pavement applications, (3) the BMPs in question involve source control activities such as street sweeping and public outreach programs, and (4) the study questions relate to BMP effects on the environment rather than just BMP performance. Watershed approaches include upstream-downstream, before-after, and paired watersheds.

Upstream–Downstream Approach

In contrast to the influent-effluent approach, the upstream-downstream approach entails a comparison of data collected from in-stream locations upstream and downstream of a BMP application. Figure 2-4 shows a schematic of an upstream-downstream approach. Station A is sited to monitor the in-stream concentration of constituents upstream of the land treatment area; Station B is sited below the BMP treatment area. Monitoring at the upstream location accounts for incoming pollutant sources that are unrelated to those that arise from within the study area. This method is more complex than the influent-effluent approach because the BMP is no longer isolated. Rather, its effectiveness must be discerned out of a data set that includes naturally occurring climatic and environmental conditions. For example, the occurrence of tributaries between the two data collection points, or changes in geology or land use can introduce variations in stream characteristics that may mask or overwhelm the effect of the BMP.

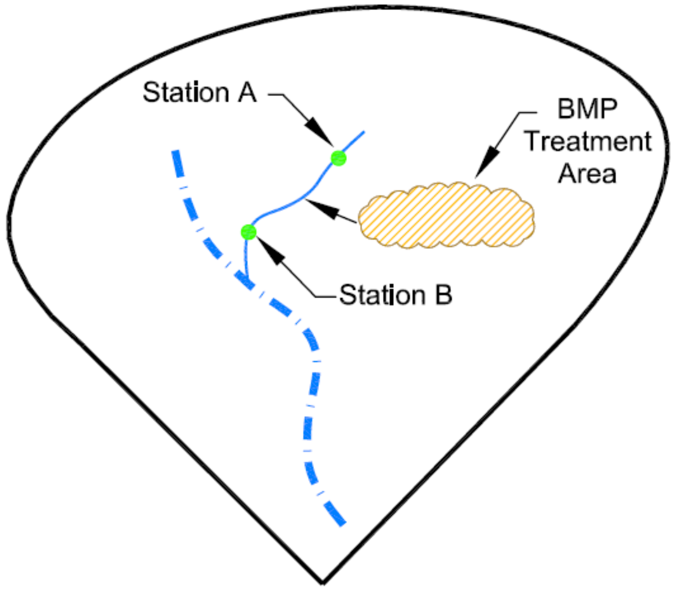
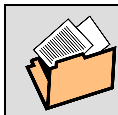


Figure 2-4 Upstream–Downstream Approach

At the very least, a relatively large data set may have to be collected to discern statistically significant effects. Yet, sampling over a long time period brings up other issues. Year-to-year and seasonal variability in water quality constituent concentrations under certain conditions may also surpass the changes caused by the BMP over any given time period. To account for some of this variability, a monitoring period of at least two to three years is recommended for both pre- and post-BMP evaluations. Care should be taken in siting monitoring locations to minimize confounding influences. Also, if time-dependent changes are anticipated (e.g., rapid urbanization of the watershed), consideration should be given to increasing the number of sampling sites in order to minimize the sampling period. Despite these potential drawbacks, if this method of monitoring is conducted properly, the results can produce evidence of BMP influence or lack of influence on the study watershed (Coffey et al. 1993).



Examples from the Files ....

Upstream-Downstream: the Small Streams Crossing Study

Although the upstream-downstream approach has not been used for Caltrans BMP testing, it was used for a characterization study known as the Small Streams Crossing Study. In this study, the study question posed by Caltrans was whether highway runoff from bridges crossing small streams on the coast had a significant impact on instream water quality. Sampling was conducted upstream and downstream of the bridge crossings for several years.

For construction projects that must comply with the General Construction Permit monitoring requirements, samples are collected within the watershed upstream and downstream of the construction site to determine if temporary BMPs are effective in controlling erosion.

Before–After Approach

In the before-after approach, data are collected at some location, a change is made (i.e., a BMP is implemented or modified), and additional data are then collected at the same location. This approach can be used to evaluate a BMP at a single location or a watershed-wide BMP program. As in the upstream-downstream approach, year-to-year and seasonal differences can have a significant influence on the results. A two- to three-year pre- and post-BMP monitoring period is recommended to account for this variability (Coffey et al. 1993). The effect of longer term climatic trends on hydrologic variability may, however, still mask the effectiveness of a BMP program. An additional shortcoming of this approach is that once the BMPs are implemented the baseline data characterization cannot be improved upon. Unrepresentative conditions during the baseline period can lead to erroneous conclusions by researchers comparing “before” and “after” data sets. For example, drought or extreme seasonal precipitation during baseline monitoring may make the baseline data unrepresentative. Also, to substantiate a cause-and-effect relationship, the predictor variable (e.g., erosion rate) must be adjusted for year-to-year changes in hydrologic conditions. Because of these problems, some experts prefer to combine this method with that of the upstream-downstream approach to strengthen the results of the findings (Coffey et al. 1993). Because hydrologic variability can occur over longer periods of time, comparative analysis of data collected using a before-after approach over the short term may actually be dealing with two distinct populations of hydrologic conditions.

> *Examples from the Files ....*
>
> **Before-After: the Public Education Study**
>
> The before-after approach was used in the Public Education Study performed in Fresno. In this study, litter was collected before and after an extensive public education program (”Don’t Trash California”) to determine if such a program could influence public behavior, and if so, to what degree would public behavior affect water quality.

Paired Watersheds Approach

In the paired watersheds approach, water quality data from two or more similar watersheds are compared. At least one is established as the control (undisturbed) watershed while the others include the BMPs being studied. Figure 2-5 shows a schematic of paired watersheds BMP monitoring. Data are collected in concurrent time periods, and changes in the data are taken as being indicative of BMP influence. In a typical paired watersheds approach, it is often desired to switch the roles of each watershed, from “control” to “treatment” and vice versa, to eliminate potential for bias. The switch may be performed on a yearly basis, or as often as needed. If properly implemented, this method provides reliable results and is perhaps the most effective watershed approach for monitoring BMP program effectiveness (Coffey et al. 1993). One weakness of this approach; however, is that it depends on the watersheds being truly similar except for the BMP. The watersheds to be compared must be in close proximity for climatic homogeneity, and have similar geology and land uses that are stable over the study period. Finding such watersheds can be difficult. Even if the watersheds appear similar, there is no guarantee that the runoff quality will be the same. For this reason, it may be advisable to undertake a calibration season in which the watersheds are sampled without any BMPs installed. While this increases the cost of the study, it also exposes any differences which could cause misinterpretation of the data from the BMP study. Finally, in this kind of study, it is important that concurrent samples are collected for comparison. The sampling program must be very reliable, which can be a challenge, especially if the watersheds are located some distance from each other.

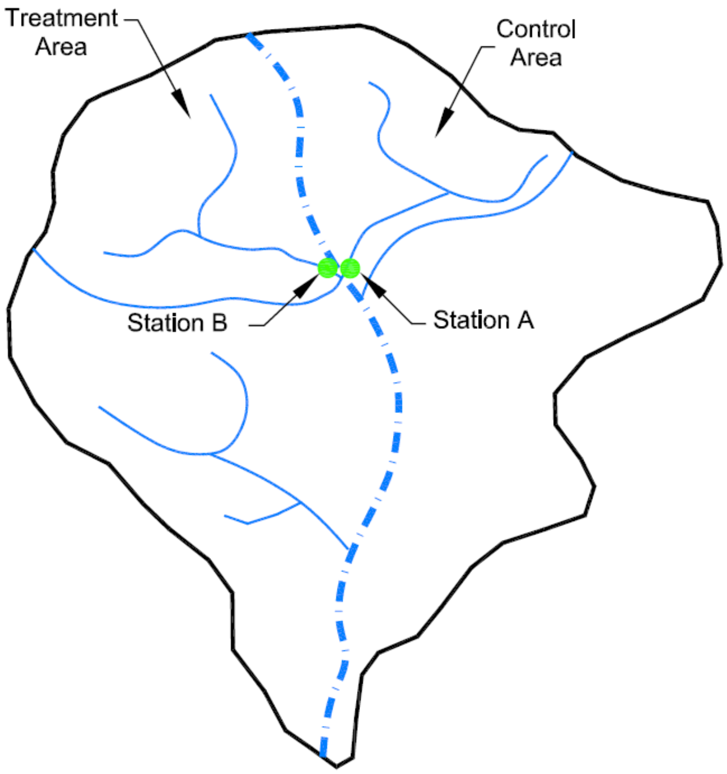


Figure 2-5 Paired Watersheds Approach

Examples from the Files ....

Paired Watersheds: DICE Study

The paired watersheds approach was used in the Drain Inlet Cleaning Efficacy (DICE) Study. In that study, water quality was measured downstream of six drain inlets that were cleaned once per year and six other drain inlets in similar catchments that were not cleaned. Midway through the study, the treatments were switched – the uncleaned inlets were cleaned and the cleaned inlets were not – to eliminate bias that might result from the paired watersheds not being identical. The effectiveness of the BMP (drain inlet cleaning) was determined by comparing the water quality from cleaned inlets with that from the uncleaned inlets.

2.1.4 Step 4: Identify Study Variables

Study variables are (1) the water quality constituents or characteristics of interest, and (2) conditions that affect the water quality data (e.g., flows, drain times, rainfall intensity, site type, and location). Identifying what type of data will be collected or monitored in the study is a critical step in the Study Plan. These can be separated into constituent data and other monitoring data.

2.1.4.1 Constituent Data

Numerical data that can be used to determine pollutant removal efficiency are required to determine the effectiveness of a BMP relative to a manufacturer's claims or industry standards. The constituents to monitor depend on the study questions. For general performance studies, the minimum constituent list in the Caltrans Comprehensive Monitoring Protocols Guidance Manual (Caltrans 2003a) might be appropriate. For more focused studies or studies driven by particular regulatory requirements, constituents might be added or subtracted from this list with approval from Caltrans. For example, turbidity is not on the minimum constituent list but is considered for pilot studies in the Tahoe Basin because it is a regulated constituent. Consideration shall also be given to how the BMP works, particularly if it is a treatment BMP, to assure that all the appropriate forms of various constituents are monitored. Quality assurance and quality control (QA/QC) procedures for data collection can be found in the Caltrans Comprehensive Monitoring Protocols Guidance Manual (Caltrans 2003a).

2.1.4.2 Other Monitoring Data

In addition to stormwater quality data, the collection of other data such as rainfall and flow time-series data, particle characterization, toxicity levels, and background concentrations of chemicals in a given study area may be necessary to answer the principal study questions and gain a better understanding of BMP performance. At a minimum, data necessary to satisfy Caltrans data reporting protocols (Caltrans 2003a) must be collected. These data include descriptions for precipitation, flow, water quality, and site characteristics for each sampling event. The data reporting protocols clearly define the data types that need to be collected for each of these categories. Additionally, data to assess pilot-specific removal efficiencies must be defined. A clear understanding of how the BMP functions in terms of unit processes (Step 2) will help in completing this step. For example, if filtration or infiltration is considered a key unit process in the BMP, then monitoring of sediment accumulation may be important to determine potential clogging and maintenance issues. Another example is collection of drain time and water level data in a basin when sedimentation is a key unit process.

2.1.4.3 Identify Variables Affecting the Data

After the PDT has determined what types of data will be collected in a study, it is necessary to identify and understand the variables that may affect these data. This understanding is vital because these variables must be accounted for in the experiment. This is the essence of a controlled experiment. Variables must be either fixed, known, or monitored. Ignoring important variables affecting the data makes interpretation of the experimental results more difficult and can lead to erroneous conclusions.

> *Examples from the Files ....*
>
> **Choosing Constituents for a Study**
>
> The choice of constituents to measure depends on the specific study questions. In the Retrofit Pilot Study, where a general measurement of BMP effectiveness was sought, twenty constituents were measured. In the Tahoe Small Scale Studies, only a few constituents were monitored because the focus was on meeting a short list of legal requirements.
>
> Thought should also be given to the treatment processes in the BMP when choosing constituents. In the Retrofit Pilot Study, the data made it appear, incorrectly, that the filters were exporting nitrogen because the sum of the nitrogen forms measured in the effluent was greater than the sum in the influent. This was because ammonia was not measured in the influent and nitrification (conversion of organic nitrogen and ammonia to nitrate) was occurring inside the sand beds. Consideration should also be given to those constituents that might be exported or artificially created by the BMP.

Examples of variables that can directly affect BMP function are listed below under various categories. Not all variables apply to all studies and the focus should be on those variables that have a direct impact on the study. Again, consideration of unit processes in the BMP is critical to identifying the key variables.

Site Characteristics

This category consists of variables that impact the quality and quantity of runoff.

Drainage Area and Slope

Data collected from assessments within a watershed can vary depending on various factors such as the location of sampling points, and size and slope of the watershed. It is important to select sampling locations where slopes, vegetation, channel width, etc., are relatively uniform and similar to the rest of the study area.

Traffic Volume

Traffic volume has the potential to affect water quality. Annual average daily traffic (AADT) is the total volume for the year divided by 365 days. The traffic count year is from October 1st through September 30th. Very few locations in California are actually counted continuously. Traffic Counting is generally performed by electronic counting instruments moved from location throughout the State in a program of continuous traffic count sampling. The resulting counts are adjusted to an estimate of annual average daily traffic by compensating for seasonal influence, weekly variation and other variables which may be present.

Vegetation and Vegetative Canopy

The amount of vegetation and vegetative overhanging canopy can change during the course of a study and may alter the results. Riparian vegetation along a creek can indirectly impact temperature and biologic parameters in receiving waters. Vegetation along a road can contribute to the gross solids loading, which might affect clogging and BMP maintenance frequency.

Percent Imperviousness, Soil Type, and Soil Compaction

Similar to other geographical or topographical variations, percent imperviousness, soil type, and soil compaction in the study area can yield variations in the data that need to be addressed during the planning of the study.

Representativeness of Inflows

Another variable to consider is whether the inflows are representative of Caltrans runoff. One factor that might affect inflow characteristics is the presence of source control BMPs or base flow that might cause the inflow to be cleaner than usual, or the presence of local sources that may make runoff more polluted than normal Caltrans runoff. An example of the latter in the Tahoe Basin is the contribution from a snow mobile rental business that resulted in much higher turbidities than expected at one media filter site. Another factor to look for is the intermingling of Caltrans runoff with runoff from other sources. In urban areas it is common for Caltrans to pipe its runoff to city stormwater sewers. In these cases, the runoff must be sampled prior to the pipe connection. In rural areas the reverse sometimes happens. Runoff from local non-Caltrans facilities mixes with highway runoff in a drainage ditch in the highway right-of-way.

BMP Characteristics

The variables in this category were identified in Step 2.

Treatment Area

BMP size is a fundamental design variable that has an impact on treatment performance. The length or area available for treatment is usually the key design variable for treatment BMPs. For source control BMPs, frequency or extent of application can be considered a key variable.

Other BMP Variables

These variables include characteristics of the soil, media, or other material that provide the treatment. For a media filter, the key variables could be the degree of pretreatment and media properties (e.g., type, grain size, uniformity coefficient, and media depth).

Storm Characteristics

This category includes variables related to storm events.

Seasonal Timing

If the study area is subject to seasonal changes or fluctuations due to particular events, this will affect the timing of data collection. Rainfall patterns vary over wide regions and consideration shall be given to the months of the year designated as "rainy season" and "non-rainy season."

Rainfall Type and Intensity

Variations in rainfall intensity and duration affect runoff rate, pollutant wash off rate, in-channel flow rate, and other phenomena that determine the pollutant concentrations, pollutant forms, and stormwater flow rates observed in a study.

> *Examples from the Files ....*
>
> **Site Variables**
>
> An example of site characteristics affecting BMP results can be found in the Gross Solids Removal Device (GSRD) Studies in Southern California. GSRDs are designed to remove gross solids, especially litter. Leaves and other vegetative debris, however, can make up a large fraction of gross solids in highway runoff. Where the vegetation was heavy, the pilot GSRDs filled up quickly and had to be cleaned before their intended service period of one year. Also, because the sources of the vegetation at the test sites were not determined, it was not possible to develop a site-specific method of sizing GSRDs to contain a year's worth of solids.

Inter-event Timing

Rain event factors such as duration, runoff volume, and inter-event timing may affect the performance of a BMP. Concentrations of pollutants measured during storm events can be useful for BMP efficiency evaluation. However, concentrations of pollutants may vary widely depending on antecedent dry period (which may result in the highest pollution concentrations during the "first flush"), duration of inter-event dry periods, and other temporal variations. These variations must be factored into the Study Plan where applicable.

Maintenance Practices

The performance of a BMP may vary with different operational and/or maintenance activities.

Operation

The operation of the BMP must be accounted for in planning the study. Unexpected problems often arise during the first year of monitoring, resulting in poor quality data or complete loss of data. Runoff from unstabilized side slopes, for example, can have an unquantifiable impact on the quality of inflows into the BMP. If the PDT has any doubt about how well a BMP will operate, it should be run with operational monitoring (e.g., water levels and flows only) for a period of time before commencing an expensive water quality monitoring program.

Maintenance

Maintenance includes cleaning and repairing equipment, vegetation control, algae reduction, sediment removal/dredging, litter/debris control, and inlet/outlet cleaning. The expected amount of maintenance required shall be taken into consideration during the planning of a pilot study and the actual amount shall be documented during the study for estimating life cycle costs.

As much as possible, the above variables shall be clearly defined in the Study Plan TM and critical variables shall be identified for data collection (discussed further in Step 6).

2.1.4.4 Check for Assumptions that Can Hide Variables

It is possible for important variables to be overlooked because of assumptions made consciously or unconsciously about sites, how BMPs work, or monitoring conditions. Common assumptions are listed below. The PDT shall check the correctness of these assumptions as they apply to the study, and shall adjust the list of study variables accordingly.

Site Assumptions

- Runoff is representative of Caltrans runoff.
- There are no unaccounted external sources. For instance, nutrient inputs from fertilizer or compost use are minimal and can be ignored.
- There is no base flow or groundwater intrusion into the BMP.

- Soil and vegetation characteristics are as expected. For example, soil infiltration rates inferred from maps are representative of actual infiltration rates.

BMP Operation Assumptions

- Installation of an impermeable liner will prevent infiltration losses from the base and sides of the BMP. This may not be the case if the liner is installed improperly or has significant tears that occur during installation.
- Bacterial growth in soil or media does not have a significant impact on the hydraulic and treatment performance of the BMP.
- There is no short-circuiting of flows within the BMP.
- Maintenance practices are carried out as needed and do not have an adverse impact on BMP operation. An example of when this may not be the case is nutrient addition due to decay of unmaintained vegetation at the surface of the BMP.

Monitoring Assumptions

- Data collected from few sites and over a relatively short time span will accurately represent how the BMP works.
- Data from grab sampling can be used to represent BMP performance.
- Monitoring that is carried out accounts for all significant inflows and outflows from the BMP.
- Events monitored are independent events.

Examples from the Files ....

Study Assumptions for Infiltration

An infiltration trench is typically a long and narrow excavation that is lined with filter fabric and backfilled with coarse aggregate. Runoff is diverted to the trench, stored in the pore space of the aggregate fill, and infiltrated into the soil. Although the infiltration trench is a Caltrans-approved BMP, deployment is hindered by its footprint requirements, determined at least partially by the amount of storage available in the rock fill. A pilot study was requested to identify alternative backfill materials to provide greater void space, thereby reducing the size of the trench. The study team identified three commercially available backfill materials for the pilot study.

The general study questions generated for the study include:

- What reduction in BMP footprint size is achievable using the new backfill materials?
- What are the maintenance requirements?
- What are the costs?

This study consists of four pilots – three to test the new backfill materials and one control with aggregate as backfill. The key assumptions in this study are described below, as are the measures taken to check or assure that the assumptions are true.

Site assumptions:

- Runoff to each pilot is representative of Caltrans runoff and comparable to that at the other test sites. This can be ensured by placing the four pilots adjacent (or close) to each other, and by selecting sites with minimal non-Caltrans drainage areas.
- There is no base flow intrusion into the pilots. Set the monitoring schedule to search for base flow during the first year of monitoring.
- Soil characteristics are as expected. Verify by including appropriate soil infiltration tests both before final site selection and after construction.

BMP operation assumptions:

- Infiltration rates are maintained during the course of the pilot study. Include monitoring for potential clogging at the soil interface.
- Maintenance practices are carried out as needed and do not have an adverse impact on BMP operation. Implement a management and reporting system to ensure maintenance practices at each pilot site are similar.

Monitoring assumptions:

- Data collected from the four adjacent sites over a relatively short time span will accurately represent how the backfill materials work. Except for size and type of backfill material, ensure the four sites are designed and constructed similarly to minimize differences.
- Monitoring that is carried out accounts for all significant inflows and outflows from the BMP. Assess by mass balance analysis of significant rainfall events.
- Events monitored are independent events. Use acceptable antecedent period criteria, and ensure that there is no standing water present between events.
- Monitoring of inflows and outflows is accurate enough for mass balance analysis to infer infiltration differences between the pilots.

2.1.5 Step 5: Specify Study Methodology

This step involves (1) deciding which study variables are to be fixed or controlled, and which ones will be will be monitored and how this will be done; (2) specifying the data collection methods and data quality objectives; and (3) determining the statistical methods that will be used for planning, interim data review, and final data analysis.

2.1.5.1 Specify How the Study Variables Will be Treated

Study parameters are characteristics or actions that are taken to fix or control study variables. For example, “representativeness of inflows” is a study variable that can be constrained by an appropriate choice of the study parameter “percentage of non-Caltrans runoff.” For the purposes of a pilot study that is of duration of no more than a few years, variables such as traffic and vegetation cover can be fixed by parameters AADT and percent vegetation density, respectively. Key variables identified in Step 4 that cannot be fixed or constrained should be monitored carefully so that their impact on the study results can be discerned at the end of the study.

Site Characteristics

During site selection, the need for controls should be considered. For study questions oriented toward general characterization of BMP performance, providing controlling variables may not be an essential part of the study. In these cases, making sure that conditions are representative or typical of Caltrans applications is more important. For study questions focused on how treatment mechanisms work, or the effects of varying design parameters, it is important to control as many of the variables as possible (ideally all of them) except for the variable under study. For example, in the SR-73 Detention Basin Study, basin size and operation mode (in-line vs. off-line) were the variables being studied. Four basins of different sizes were designed in in-line mode to isolate basin size as the study variable. To study off-line operation required four additional basins of the same sizes as the first four but in the off-line mode. To control for weather, the eight basins were located as close to each other as practical. As this example shows, the need to provide controls will influence the number of basins needed for the study.

Drainage Area and Slope

These can be constrained as necessary to meet the study objectives. If the objective is to study the effect of a design parameter, for instance, only a few representative drainage areas need to be studied. If widespread testing of the BMP under the full range of Caltrans conditions is desired, a range of drainage areas can be specified.

Traffic Volume

Traffic volume should be considered when selecting sites because it has the potential to affect inflow quality. Sites with more than 30,000 vehicles per day are characterized as high AADT; sites with 30,000 or less vehicles per day are characterized as low AADT.

Vegetation and Vegetative Canopy

If the presence of vegetation is likely to adversely impact the study results, sites should be selected where vegetation is minimal, or maintenance procedures should be initiated to control the level of vegetation during the study period. Alternatively, sites with very similar vegetation can be chosen and maintained (or not) in identical fashion.

Percent Imperviousness, Soil Type, and Soil Compaction

These can be constrained as necessary to meet the study objectives. Soil characteristics are critical in siting infiltration type BMPs – site selection for these should follow Caltrans procedures specified in the Project Planning and Design Guide (PPDG) (Caltrans 2007).

Representativeness of Inflows

It is desirable to select sites where inflows are representative of Caltrans runoff. This may require field surveys to ensure that potential sites meet this requirement, since some inflow sources may be seasonal. It also requires consideration of traffic volume (see above). In the Highway 50 Activated Alumina Filter Pilot Study, for example, one site had seasonal base flow that significantly impacted inflow quantity and quality.

Site Characteristics Affecting Monitoring

Monitoring sites must facilitate representative sampling and flow measurement. The following criteria should also be considered in the selection of monitoring sites:

- Monitoring sites shall be located where flows (inflow, outflow, overflows, bypasses, or in-stream flows) are relatively uniform and stable or can be made relatively uniform and stable using control features so that accurate flow measurements can be made.
- Sites likely to be affected by backwater and tidal conditions shall be avoided.
- Monitoring sites shall be accessible, well-secured, and large enough to accommodate monitoring equipment such as flumes.
- Monitoring sites need to be located where field personnel can be as safe as possible.

Further discussion of siting criteria can be found in Section 3.2.1 of the ASCE Urban Stormwater BMP Performance Monitoring Manual (ASCE 2002), and Section 3 of the Caltrans Comprehensive Monitoring Protocols Guidance Manual (Caltrans 2003a).

BMP Characteristics

This category includes the physical design features identified in Step 4.

Treatment Area

Most BMPs are sized based on either water quality volume or water quality flow. The basis for sizing the BMP should be stated clearly, together with deviations from standard sizing methods. For example, the media area at one of the Highway 50 Activated Alumina Filter Pilot Study sites was reduced to one-third of the calculated design area (based on standard Austin-style sand filter design) to purposely increase loading and provide a quicker determination of media life. Refer to the Caltrans PPDG for sizing parameters, safety features, and other issues (Caltrans 2007).

> *Hypothetical Example* ?
>
> **A Media Comparison Study**
>
> An alternative media filter study is proposed to test the difference in treatment provided by sand and limestone. The following design parameters are recommended based on a review of BMP treatment mechanisms:
>
> Degree of pretreatment:
>
> - Pretreatment required – Design as partial sedimentation Austin-style filters following Caltrans guidance in the PPDG (Caltrans 2007).
>
> Media properties:
>
> - Type – Provide clean Monterey sand at Site 1 and clean limestone at Site 2.
> - Grain size and uniformity coefficient – Ensure the mesh size is no smaller than 28x14 and the uniformity coefficient is not larger than 3. Grain sizes for both media should be similar to minimize variations in treatment performance due to grain size and facilitate comparisons between the two media.
> - Media depth – Both filter beds should have identical depths that might be based on the head available at representative sites where BMPs could be deployed.

Other BMP Parameters

The characteristics of the soil, media, plants, or other material that provide the treatment, and that reduce the flow volume and rate should be defined as necessary to meet the objectives of the study. Soil characteristics include texture, erosion potential (erodibility), infiltration qualities, and the ability to establish vegetation (e.g., fertility and amount of organic matter). Media characteristics include type (e.g., sand, peat, compost, perlite, zeolite, carbon, and other “exotic” media), and its physical and chemical properties. Plant characteristics include type, cover, need for irrigation, etc. For studies intended to determine how variations in design parameters affect performance, care should be taken to control the variables not under study. An example is given in the text box for a hypothetical pilot study comparing two alternative media filters.

Construction

Construction parameters include key construction features that need to be identified to ensure they are constructed or installed carefully. A review of the unit processes and treatment mechanisms described in Step 3 may be helpful here. For example, soil compaction must be minimized at sites where infiltration may be an important treatment mechanism. This can be done by prohibiting the use of heavy machinery and by specifying alternative construction methods. Another example is the requirement that manufacturer's guidelines be followed for media installation where filtration is the treatment mechanism. Poor media installation has caused settling to occur and may have been responsible for short-circuiting of flows in previous pilot studies.

Further discussion on key construction features is provided in Chapter 6.

> *Examples from the Files ....*
>
> **Unusual Hydrology**
>
> Unknown or unusual flows affect the interpretation of experimental results. For the Los Angeles River trash TMDL, litter was to be captured from all storms up to the 1-year, 1-hour event. In the Gross Solids Removal Device (GSRD) Studies, flow monitoring equipment was not installed because water quality samples were not collected. Researchers could see that the GSRDs occasionally overflowed because there were solids in the overflow bags, but they could not determine what size storm caused overflow, and therefore, could not determine if the devices were adequately meeting the TMDL standard.
>
> In the SR-73 Detention Basin Studies, the rainfall for the first monitoring year (2004-05) was unusual in the sense that the rain fell predominantly during large and intense storms. Not only was the rainfall unrepresentative of the project site, but the solids loading was also unusually high because the slopes in most catchments had not stabilized after construction.

Monitoring

Monitoring parameters include the storm characteristics identified in Step 4 and the frequency and number of storms. Seasonal timing and frequency of monitoring activities is based on the appropriate number of random samples that need to be collected to characterize the rainfall and seasonal patterns associated with the monitoring site. Estimates of the number of samples required to yield statistically valid monitoring results are also necessary for making decisions about the nature and extent of monitoring efforts. The appropriate number is the number of samples required to discern a significant difference between influent and effluent or between effluent and a numeric limit.

Seasonal Timing

Rainfall and seasonal patterns vary greatly in California and consideration shall be given to the months of the year that are designated "rainy season" and "non-rainy season" within each region of the state. To account for the various rainfall patterns (e.g., time frame, intensities, and amounts), the state is separated into several rainy seasons, as follows:

- Northwestern and Southwestern California, rainy season: October 1 through May 1.
- Northern and Central California, rainy season: October 15 through April 15.
- Eastern California, rainy seasons: August 1 through October 1, and November 1 through May 1.

Rainfall Type and Intensity

Establishing appropriate storm selection criteria can be a challenge. Ideally, one would want to obtain data from several phases of each storm for as long a study period as possible. The reasons for doing this are:

- To learn how the BMP performs during periods of low, medium, and high flows. The performance of some BMPs can vary dramatically with throughput rate.
- To provide statistical confidence in estimating performance based on widely varying runoff flows.
- To characterize the water quality of dry weather flows for those BMPs that rely on base flow (e.g., constructed wetland) or standing water (e.g., wet ponds). This is particularly important when the water quality volume of the BMP is large relative to storm events. In such a facility, comparing inflow to outflow during a storm event is not valid because the outflow may have little or no relationship to the incoming storm.

Setting storm event criteria is a complex process that is affected by the study goals, local climatic factors, permit requirements, and the BMP itself. The first consideration is whether the study goals require "representative" or "worst-case" events to be monitored.

Deciding storm representativeness requires consideration of storm size and antecedent dry period. If representative storms are desired, most storms occurring in the study period (except unusually large ones) would be monitored. If the objective of the monitoring is to consider a "worst-case" scenario, it would be desirable to select storms with the highest pollutant concentrations rather than a representative mix of storms. Worst-case conditions are likely to occur after long antecedent dry periods (72 hours to 14 days). Therefore, if feasible, storms would be selected with antecedent periods greater than 72 hours. Biasing storm selection to the "worst case" would not provide a representative sample of the population of all types of storm events and shall not be used to estimate statistically-derived exceedance frequencies. Local climatic factors also need to be considered in judging representativeness. In some climates, the majority of the rainfall may come in small events; in others, the majority may arrive in large events.

Monitoring plans and equipment may be different for each situation. Flow measuring equipment generally has a limited range of effectiveness. Primary flow montoring devices (flumes and weirs) should be sized to rate the expected range of flows. Primary flow monitoring devices should be sized to rate the lowest flow possible. Primary flow measurement devices should also be sized for the flood design event (refer to Chapter 800 of the Highway Design Manual) so that they do not cause an obstruction in the stormwater conveyance system, which could cause flooding or result in flows overtopping the device. The Isco Open Channel Flow Measurement Handbook, Sixth Edition is an excellent resource that can be used to select and size a primary flow measurement device. Flumes sized to measure large flows, for instance, usually cannot accurately measure very small flows and vice versa. Regulatory requirements can be another consideration. In many locations, stormwater treatment requirements may apply to storms only up to a given size. Therefore, determining performance in large storms may not be of interest.

Finally, it should be remembered that the BMP itself may influence the storm criteria. For instance, in very small events, detention basins will often not produce a measurable effluent because of infiltration.

Lacking any criteria for storm volume selection to capture the worst-case conditions, and acknowledging that storm characteristics are highly dependent on climatic region, the following criteria may be used as a starting point in storm selection:

- Rainfall volume: 0.10 inch minimum, no fixed maximum.
- Rainfall duration: No fixed maximum or minimum, typical range 6 to 24 hours.

For the purposes of this Manual, a precipitation event shall begin with six consecutive hours during which a sum total of at least 0.1 inch of rain falls, and end with six consecutive hours in each of which no rainfall greater than 0.01 inch of rain is recorded. The precipitation event so identified shall be truncated so that it both begins and ends in hours with rainfall equal to or greater than 0.01 inch.

Further discussion can be found in Section 3.2.5 of the ASCE Urban Stormwater BMP Performance Monitoring Manual (ASCE 2002) and Section 9 of the Caltrans Comprehensive Monitoring Protocols Guidance Manual (Caltrans 2003a).

Number of Storms and Frequency of Monitoring

Because of the variability of rainfall and runoff quality, it is necessary to sample a number of storms to generate statistically reliable answers to the study questions. The number of samples needed depends on the variability in the data, the magnitude of the effect being studied, and the degree of confidence desired in the answer. For instance, suppose the study question involves the effectiveness of a BMP and differences between influent and effluent samples are being examined. Other factors being equal:

- More samples are needed when the data are variable than when they are not.
- More samples are needed when the differences between influent and effluent are small than when they are large.
- More samples are needed to establish a high degree of confidence than a lower one.

> *Examples from the Files ....*
>
> **Number of Data Points Needed to See Differences**
>
> Where data sets contain large variations, many samples are required to demonstrate statistically significant results. For instance, in the Retrofit Pilot Study, the mean effluent values for coliform bacteria were 90 percent lower than the influent values, but the removal could not be considered to be statistically significant because only four coliform bacteria samples were collected. Choosing the right number of data points can be a complicated decision. In the DICE Study, litter discharges from drain inlets were initially judged to be the same regardless of whether the inlets were cleaned or not (based on about 50 samples). The fact that litter accumulated in the cleaned inlets (and was therefore removed from the flow by definition) was not reflected in the discharge statistics. Another year of litter monitoring was required to establish a clear statistical difference.

A statistical methodology for determining the number of samples needed is presented in Appendix K1. Typically, Caltrans BMP studies look for a minimum change, Δ, of 50 percent at a confidence level (1-α) of 90 percent. In some studies, such as those where BMP effluents are close to regulatory limits, or where the BMPs being studied are thought to be working poorly, detecting smaller Δ values might be appropriate. To be considered for approval, however, a new BMP needs to show a practical level of effectiveness. In most cases, new BMPs would not be adopted if they did not remove a significant fraction of the constituent of concern. The most commonly used confidence level in scientific studies is 95 percent. Because of the high variability in stormwater data, however, using a 95 percent confidence level results in an impractical number of samples or masks the effectiveness of BMPs known to remove pollutants (Caltrans 2004a). For this reason, a <u>90 percent</u> level should be used in Caltrans BMP studies. Additional discussion of the statistical methods available for estimating the number of observations (i.e., samples) can be found in Section 3.2.2.2 of the ASCE Urban Stormwater BMP Performance Monitoring Manual (ASCE 2002).

Once the number of samples needed is calculated, the length and number of sites for a study can be determined. Table 2.1 summarizes the number of storms and average rainfall depth per storm for several locations around California. As shown in the table, the average number of storms occurring each year decreases with increasing minimum storm size, increasing minimum dry time between events, and decreasing latitude. Lacking more site-specific data, this table can be used as a planning tool. After the minimum storm size to be monitored, the minimum dry period defining the break between storms, and the location are chosen, the number of storms per year and the average storm size can be estimated using the table. For example, if the storm event criteria are a minimum storm size of 0.25 inches with at least 24 hours between storms, then an average of 15 storms per year could be expected for a site in Sacramento, and an average of 10 storms per year could be expected for a site in San Diego. If the statistical calculations suggest that 30 storm events are needed to answer the study questions, a study based in Sacramento would require two years and one based in San Diego would require three years. In general, Caltrans has conducted three-year pilot studies to ensure data collection during representative weather, although study durations should depend on data variability and statistical considerations. On the lower end, study periods shall not be less than one year at any location so that the variability from seasonal changes or fluctuations can be captured.

Number of Sites

The number of sites that need to be monitored depends on program objectives, type of study, need for control sites, size and complexity of the drainage basin(s), and resources (time, personnel, funds) available for monitoring. In addition, the frequency of sampling at each location must be considered. Depending on objectives, resources, and logistical considerations, many locations may be sampled infrequently, or fewer locations more frequently. Sampling many locations is generally better for evaluating geographic variability as it affects climate and/or runoff characteristics. This strategy would be employed if a study goal is to assess the wide-scale applicability of a BMP. Sampling a few locations for longer periods is generally better for evaluating BMP effectiveness over time and for characterizing specific monitoring locations (e.g., sensitive water bodies) more accurately. The PDT shall consult with Caltrans to determine the number of sites proposed for the study, and using statistical analysis (Appendix K1) shall estimate the number of data points and sites required for a given length of study.

Study Period vs. Number of Test Sites

Statistical considerations dictate the number of samples needed to discern an effect given certain variability in the data (see Appendix K1). Whether these samples are collected at a few sites for a long time or at many sites for a short time is a Study Plan decision. Sometimes the study questions include geographic and temporal aspects that fix the number of test sites or the length of the study period. For instance, it may be a study goal to determine how a particular BMP performs in a variety of typical California climates. Or, a goal may be to finish the study within a certain time to meet a regulatory requirement. If the study does not have these kinds of restrictions, however, there may be flexibility in planning pilot facilities – many installations with a short monitoring period or fewer installations with a longer monitoring period.

In calculating sampling costs, consideration must also be given to the number of unproductive events that are likely to occur. Sometimes rainfall does not occur as predicted or does not occur in sufficient quantities to justify sampling. Samples can also be missed because of mechanical problems with automatic samplers. For planning purposes, it is reasonable to assume that one out of four sampling attempts will be unsuccessful.

Table 2.1 Number of Storms and Average Rainfall Depth per Storm as a Function of the Minimum Storm Size and the Minimum Dry Period Defining the Separation between Storms

		Minimum Dry Time Between Storm Events					
		6 hours		24 hours		72 hours	
Rain Gauge Location	Gauge No.	Avg. No. of Storms per Year	Avg. Storm Depth (inch)	Avg. No. of Storms per Year	Avg. Storm Depth (inch)	Avg. No. of Storms per Year	Avg. Storm Depth (inch)
Minimum Storm Depth = 0.1 inch							
Redding	7295	39	0.68	24	1.07	15	1.73
Sacramento	7630	28	0.54	20	0.77	13	1.21
Oakland	6335	29	0.54	21	0.78	13	1.27
San Francisco	7769	33	0.58	23	0.86	14	1.43
Fresno	3257	25	0.41	18	0.58	13	0.83
Los Angeles	5114	18	0.65	14	0.85	11	1.14
San Diego	7740	19	0.48	14	0.65	11	0.87
Minimum Storm Depth = 0.25 inch							
Redding	7295	24	1.01	18	1.41	11	2.26
Sacramento	7630	19	0.74	15	0.98	10	1.48
Oakland	6335	19	0.75	15	1.01	10	1.58
San Francisco	7769	21	0.81	17	1.13	11	1.77
Fresno	3257	14	0.59	13	0.76	10	1.04
Los Angeles	5114	12	0.90	10	1.10	8	1.42
San Diego	7740	12	0.68	10	0.86	8	1.12

Table 2.1 Number of Storms and Average Rainfall Depth per Storm as a Function of the Minimum Storm Size and the Minimum Dry Period Defining the Separation between Storms (Continued)

		Minimum Dry Time Between Storm Events					
		6 hours		24 hours		72 hours	
Rain Gauge Location	Gauge No.	Avg. No. of Storms per Year	Avg. Storm Depth (inch)	Avg. No. of Storms per Year	Avg. Storm Depth (inch)	Avg. No. of Storms per Year	Avg. Storm Depth (inch)
Minimum Storm Depth = 0.5 inch							
Redding	7295	17	1.29	14	1.69	10	2.63
Sacramento	7630	11	1.01	10	1.28	8	1.84
Oakland	6335	10	1.05	10	1.36	7	1.99
San Francisco	7769	13	1.10	12	1.44	8	2.19
Fresno	3257	7	0.88	8	1.01	7	1.33
Los Angeles	5114	8	1.21	7	1.45	6	1.82
San Diego	7740	6	0.97	6	1.18	6	1.49

Source: Scott Meyer, Office of Water Programs, California State University Sacramento, based on data contained in Hydrosphere Data Products. 2005. Climate data NCDC Hourly Precipitation - West, Volume 15.2. Hydrosphere Data Products, Boulder, Colorado.

2.1.5.2 Specify the Data Collection Methods and Analytical Approach

Once the study parameters are defined, appropriate data collection methods are specified. This includes the types of samples to be collected and sample collection techniques. The method of data collection will depend on various factors, including the study goal, regulatory requirements and/or recommendations, QA/QC considerations, time constraints, available budget, and the constituents to be analyzed.

In general, flow-weighted composite sampling is recommended over grab sampling. Collecting grab samples from a heterogeneous stream or discharge can compromise sampling precision and sampling accuracy, and result in unreliable data. Moreover, a grab sample does not represent a continuous stream if it has not yet proven to be homogenous. In composite sampling, a number of aliquots[3] are collected from the discharge stream and combined into a single sample. The single sample is then analyzed for the chemical contaminant of concern. While there are several methods for deciding when to collect aliquots and how large they should be, the preferred

[3] An aliquot is a known volume of liquid that represents a part of some larger volume. In this context, it is one of the small volumes periodically collected from the waste stream that are then combined to make the composite sample.

method in most Caltrans studies is to use volume-weighted or flow-weighted sampling. That said, there are occasions when grab sampling is appropriate. Composite samples characterize average conditions within a runoff event. To determine how characteristics change throughout a storm, for instance to see the "first flush," grab sampling is needed. Grab sampling is also needed for certain constituents for which accurate samples cannot be collected using standard automated composite sampling equipment. Among others, these constituents include bacteria, ammonia and volatile organics, and oil/grease.

Specific procedures for sample collection and data quality assurance will be developed and specified in the OM&M Plan (Chapter 7). Detailed descriptions of accepted sampling procedures can be found in the Caltrans Comprehensive Monitoring Protocols Guidance Manual (Caltrans 2003a).

2.1.5.3 Statistical Methods

Statistical methods provide a useful tool to address important issues in three different stages of typical BMP pilot studies – planning, interim data review, and final data analysis. Figure 2-6 presents a flowchart of the main tasks associated with each of these three stages. A summary of typical study questions in BMP pilot studies and the applicable statistical methods is presented in Table 2.2. For each method, Table 2.2 also identifies the applicable appendix that provides details on its application to address the study question of interest. Table 2.3 provides a cross-reference to the title of each appendix and the topics covered in it. The intended audience for the appendices is engineers and scientists who have little or limited background in statistics. Accordingly, the focus is not on the theory of the statistical methods, but rather on the selection of an appropriate statistical method, interpretation of results, understanding of the limitations of the analysis method, and drawing of valid conclusions. Detailed descriptions of the statistical methods are provided in Appendix K. Descriptions of the statistical analysis tasks for the interim and final reports are contained in Chapter 8.

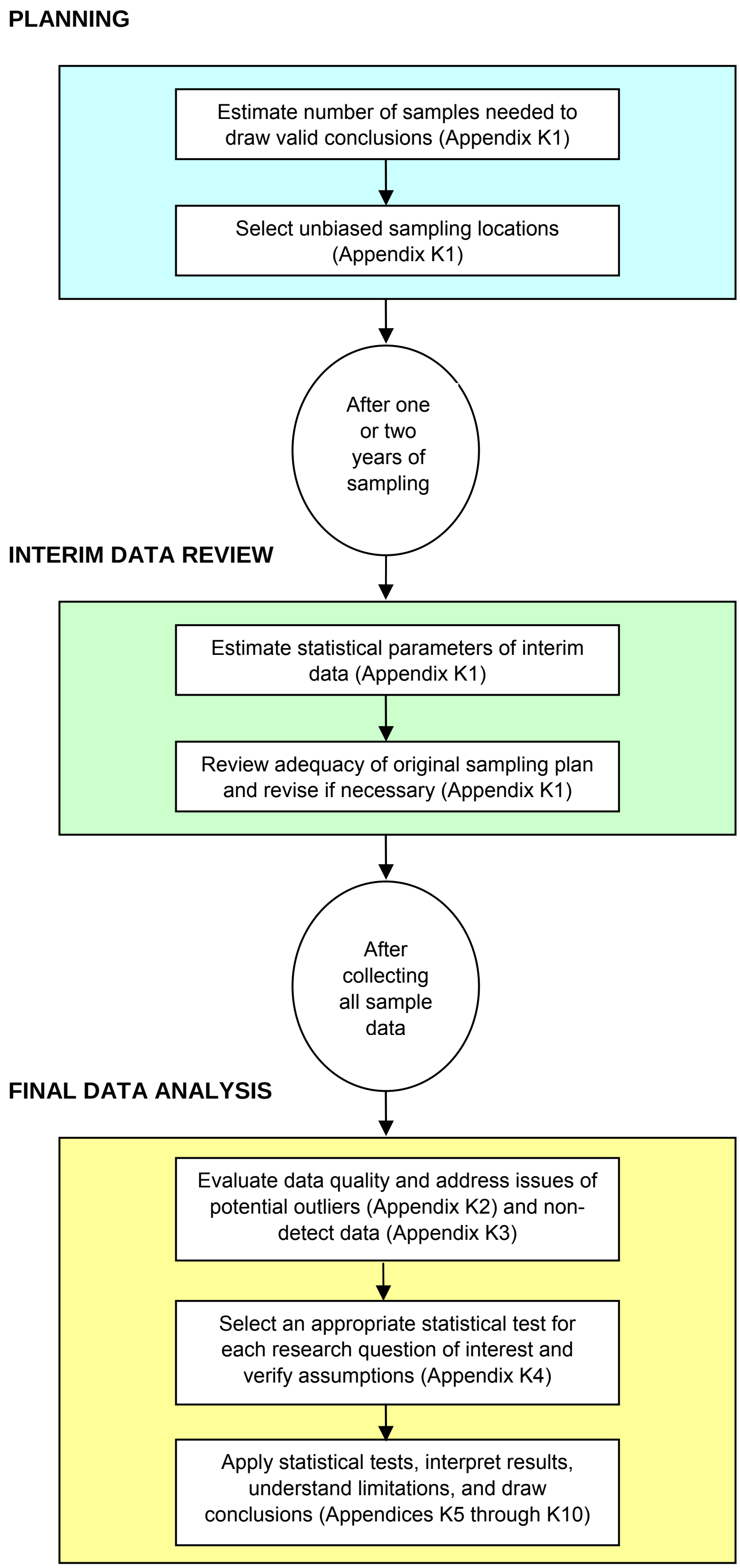


Figure 2-6 Flowchart of Statistical Analysis Tasks

Table 2.2 Typical Study Questions and Applicable Statistical Methods in BMP Pilot Studies

Study Question	Applicable Method	Appendix
Sampling Plan Issues		
How many samples do I need to be able to detect a specified percentage removal of pollutant?	Decision error control method for two paired groups	Appendix K1
Influent-Effluent Approach or Before-After Approach		
Upstream-Downstream Approach or Paired Watershed Approach	Decision error control method for two independent groups	
Given a number of samples (e.g., after a year or two of sampling), have I sampled a sufficient number of events to draw conclusions on treatment performance? How many more do I need?	Same methods as above	Appendix K1
Evaluation of Differences among Data Sets		
Comparing the effluent concentrations of a BMP against a legal limit, how often will the BMP meet this limit?	Confidence limit on the mean effluent concentration	Appendix K5
For pollutant concentrations measured with an influent-effluent or before-after monitoring approach, does a BMP remove a pollutant by more than a specified percentage?	Comparison of two paired groups	Appendix K7
For pollutant concentrations measured with an upstream-downstream or paired watershed monitoring approach, does a BMP remove a pollutant by more than a specified percentage?	Comparison of two independent groups using Analysis of Variance (ANOVA)	Appendix K6
Given influent and effluent data for three pilot BMPs of the same type, how can I tell whether they are all operating in an equivalent manner, or whether there is some site-specific factor that causes one BMP to operate differently than the others?	Comparison of three (or more) independent groups using Analysis of Variance (ANOVA)	Appendix K8
Four pilot sites are close to each other. Are the influent water quality characteristics different from each other or essentially the same?	Comparison of four independent groups using Analysis of Variance (ANOVA)	Appendix K8
General Data Issues		
How do I deal with "non-detect" results – in general and according to Caltrans protocols?	Methods dealing with censored data	Appendix K3
I have what looks like an extreme event. . What should I do with the unusual or unrepresentative data? Can I ignore it?	Identification of potential outliers	Appendix K2
It appears that some of my measurements are incorrect because of a systematic error. . If I adjust the data set to compensate for the error, how does that affect the statistical conclusions?	Consult a statistician	--
I have groundwater intrusion (or non-Caltrans surface water) at one of my sites. . Is there a statistical method to help me separate the characteristics of the flow I am interested in from the mixed flow? How many data points of the unwanted flow must I collect?	Consult a statistician	--
Under what conditions can I lump together data from different experiments? When shouldn't I do this?	Comparison of multiple groups using ANOVA	Appendix K6 or K8

Table 2.2 Typical Study Questions and Applicable Statistical Methods in BMP Pilot Studies (Continued)

Study Question	Applicable Method	Appendix
Relationships between BMP Performance and Other Factors		
How can I tell if the effectiveness of my pilot BMP is changing over time?	Trend analysis	Appendix K10
How do I derive predictive relationships between the concentration of one constituent and one or more other constituents or variables? Examples: Does effluent concentration vary with flow? Do runoff concentrations depend on the frequency of sweeping or the time since the last sweeping or the time since the last rainfall?	Linear regression	Appendix K9
I have collected data from three pilots of different sizes (e.g., area of filter per unit area of catchment). . How do I determine the proper size for BMP design from these data?	Linear regression	Appendix K9
How does effectiveness vary with various input concentrations?	Linear regression	Appendix K9
How does effectiveness vary with storm characteristics such as rainfall amount, rainfall intensity, and antecedent weather conditions?	Linear regression	Appendix K9
How do design variables (e.g., area of filter fabric, length of infiltration trench, etc.) affect performance?	Linear regression or ANOVA	Appendix K9 Appendix K6 or K8
How does effectiveness vary with different operational and/or maintenance approaches?	Linear regression or ANOVA	Appendix K9 Appendix K6 or K8
Other Questions		
Comparing the effluent concentrations of a BMP against a legal limit, how often will the BMP meet this limit?	Confidence or tolerance limit	Appendix K5
How does the BMP's treatment efficiency and performance compare to other BMPs?	Comparison of multiple groups	Appendix K6 or K8
Does the BMP cause an improvement in or protect downstream beneficial uses?	Comparison of two paired groups	Appendix K7
Does the BMP have potential vector control or negative downstream impacts?	Comparison of two paired groups	Appendix K7

Table 2.3 Topics Covered in Each Appendix

Appendix	Title	Typical Study Questions Addressed
K1	How to Estimate an Adequate Number of Samples	How many samples would I need to achieve desired confidence in the conclusions? After one or two years of sampling, how do I decide whether I would need more samples than initially planned?
K2	How to Examine Data Quality and Detect Possible Outliers in the Data	How do I prepare graphical and numerical data summaries to understand salient data features and identify potential outliers?
K3	How to Examine Data Quality in the Presence of Non-detect Values	How do I account for non-detect results?
K4	How to Verify Common Assumptions for the Selection of an Appropriate Statistical Test	How do I verify whether data are normally distributed? How do I verify that the data variability of two or more groups is similar?
K5	How to Estimate Probabilities Using Data for a Single Variable	How do I estimate how often the average BMP effluent concentration would meet a legal limit? How do I estimate the BMP percentage removal of a pollutant with a specified confidence level?
K6	How to Compare Two Independent Data Sets	In an upstream-downstream watershed approach or paired watersheds approach, how do I decide whether a given BMP is effective in removing a pollutant? How do I compare the effectiveness of two pilot BMPs at a given geographic location?
K7	How to Compare Two Paired Data Sets	In an influent-effluent approach or before-after approach, how do I decide whether a given BMP is effective in removing a pollutant?
K8	How to Compare Three or More Independent Data Sets	How do I compare the effectiveness of three or more pilot BMPs at a given geographic location?
K9	How to Develop a Linear Regression Equation	How does BMP effectiveness vary as a function of such other factors as storm characteristics, BMP design variables, and operation/maintenance practices?
K10	How to Evaluate Time Trends in BMP Monitoring Data	How can I tell if the effectiveness of my pilot BMP is changing over time?

2.1.6 Step 6: Optimize and Validate the Study Plan, WBS 150.15

At the end of the planning process, it is valuable to assess the whole effort and decide whether the draft final plan is as efficient as it can be and whether it still meets the objectives established at the beginning. Furthmore, it is important to compare the estimated cost to perform the study with the available budget. The Study Plan should include a cost estimate based on best engineering judgement for all components of the study that have been planned and optimized (including designing, construction, monitoring, and reporting).

2.1.6.1 Alternative Outcomes Analysis and Study Assumptions

To check whether or not the study goals or study questions will lead to answers that effectively address the Department’s needs, the PDT should explore the range of alternative outcomes to each study question. For each outcome, the meaning of that outcome with respect to the study goals and Department needs should be examined. For example, a study question might be how well a filter removes a certain constituent. One outcome is that the constituent is effectively removed; another outcome is that the constituent is not effectively removed. In this case a positive outcome might lead to approval of the BMP and a negative outcome might lead to the BMP's rejection. What the PDT should be looking for are situations where (1) alternative outcomes to a study have the same or no impact on the Department need, or (2) alternative outcomes are inconclusive. In these cases, the study goals or questions need to be revisited and revised or augmented. Sometimes an outcome may not solve the Department's ultimate problem, but may lead to an obvious follow-up study question. For instance, at Lake Tahoe where the effluent turbidity requirement is 20 NTU, one possible outcome is that the BMP removes a substantial fraction of the influent turbidity, but the effluent concentration is not as low as 20 NTU. The follow-up study question is whether there is some modification to the BMP that would improve its performance (e.g., increasing the depth of a filter media bed or changing its hydraulic loading).

Alternative outcomes analysis is not needed for every study question. It is most appropriate for hypotheses that have "either or" answers. Alternative outcomes do not need to be considered for questions that are primarily oriented toward data collection. For example, a common study question is, "How much does this BMP cost?" There are no competing alternative outcomes to be analyzed. In contrast, alternative outcomes would have meaning for a study question like, "Does this BMP meet the phosphorus standard in 90 percent of storms?"

Examples from the Files ….

Alternative Outcomes Analysis for Pilot Study of Groundcover and Low-growing Shrub Vegetation Treatment of Highway Runoff

The purpose of the Groundcovers and Low-Growing Shrub Vegetation Types in Biostrips and Bioswales for Storm Water Treatment Pilot Study is to investigate the effectiveness of existing landscapes within the Caltrans right-of-way where groundcover and low-growing shrub vegetation may be providing treatment of highway runoff that is functionally equivalent to biostrips and bioswales designed as BMPs. Below are examples of alternative outcomes for some of the study questions:

1) Do existing sites, vegetated with groundcovers or low-growing shrubs, within the Caltrans right-of-way provide a significant reduction in pollutants in highway storm water runoff?
    Outcome 1: A significant reduction is considered 50 percent based upon other BMP pilot study designs. If the removal of target constituents is greater than 50 percent of the influent constituent loading, it should be considered that the system meets this criterion.
    Outcome 2: If the removal of target constituents is less than 50 percent, the vegetated system should not be considered effective, and treatment credits would not be anticipated.

2) Do these areas provide functionally equivalent treatment when compared to engineered bioswale/biostrip systems?
    Outcome 1: If the percent reduction in pollutants from existing systems with established vegetation is statistically similar to the percent reduction in pollutants of designed BMPs, then the Pilot Study should be considered a success in meeting this criterion.
    Outcome 2: If the percent reduction in pollutants from existing systems with established vegetation is significantly less than that of designed BMPs, then the vegetated areas should not be considered functionally equivalent to engineered biofiltration systems.

3) What is the effect of regional climatic differences on the performance of these existing vegetated areas?
    Outcome 1: If the vegetated systems perform equally well among most sites in both northern and southern California, then performance of existing vegetated areas should be considered similar for a corresponding range of climatic settings. However, application in cold weather climates that are subject to snow removal activities may need to be evaluated separately.
    Outcome 2: If the existing vegetated areas do not perform well among most sites within one region due to climatic factors, then consider obtaining credit for treatment for sites only in locations with climates similar to the pilot locations that showed successful treatment, as evaluated by study questions 1 and 2.

Examples from the Files ....

Examining Study Assumptions

In the SR-73 Pilot Detention Basin Project, the overarching project need (Step 1) was guidance on designing and deploying detention basins in locations where there was insufficient space to build a detention basin that would capture the full Water Quality Volume (WQV).

One study question (Step 2) was: "How does treatment performance vary with basin volume?" The underlying hypothesis is that the primary treatment mechanism in detention basins is sedimentation and that sedimentation performance is related to detention time. The relationship between detention time and basin volume, however, is an assumption. Because rainfall intensity patterns and the size of the outlet orifice affect detention time, the relationship between basin size and detention time is not direct and may be influenced by these other factors. For example, to drain a large detention basin in 48 hours (to prevent mosquito breeding) requires an outlet orifice of a certain size. Most storms, though, are small and the runoff will pass very quickly through a large basin because of its relatively large orifice. In this example, the study question "How does treatment performance vary with basin volume?" can not be fully answered unless comparisons are made between sites which have similar outlet orifice sizes relative to their drainage areas, and storms with similar rainfall intensity patterns are monitored. Examining study assumptions in this way can be useful in further checking the study variables and study questions.

2.1.6.2 Practical Constraints on Data Collection

The number of monitoring sites and events are dictated by the number and types of data points required to provide statistically significant answers to the key study questions. As emphasized earlier, the number of samples needed to characterize a particular condition can be estimated by mathematical equations that take into account types of errors associated with a typical study, degree of confidence, the probability distribution (e.g., normal, log-normal, etc.) that fits the data, and other variables. Unfortunately, sample numbers are usually not based on a statistical process and instead, are determined by professional judgment, or are resource-driven. Resources are never infinite and Study Plans must often be adjusted to accommodate resource availability.

In developing the Study Plan to this point, a set of performance or acceptance criteria that the pilot study will need to achieve has been generated. The goal of this step is to optimize the Study Plan by developing an effective design for collecting and measuring environmental samples, or for generating other types of information needed to address the Study Plan objectives. This corresponds to producing either (a) the most resource-effective data collection process that is sufficient to fulfill the study objectives, or (b) a data collection process that maximizes the amount of information gathered within a fixed budget.

2.1.6.3 Iterating the Study Plan to Match Available Budget

Having sufficient funding available to complete the ideal study is rare. Collecting enough data to answer questions regarding BMP performance or environmental effects with a high level of statistical confidence is generally expensive and time-consuming. Consequently, the Study Plan will often have to be revised to fit within the available budget. Reductions in scope shall be done in a careful manner based on an analysis of the effects on the study's ability to answer the study questions (see Figure 2-1). Suppose, for example, that the costs of a study involving four sites and 30 samples per site needed to be reduced by half. One strategy would be to reduce the number of samples to 15 each at all four sites. Doing this, though, would increase the probability of drawing an incorrect conclusions from the statistical analyses of the experimental results. An alternative strategy would be to drop two of the sites but collect 30 samples at each. Doing this, though, would limit the ability of the study to determine the BMP's performance under different conditions (e.g., climatic factors, runoff characteristics, traffic volumes). How the BMP might perform at the two dropped sites would not be known. If a BMP's performance is expected to vary greatly with differing site conditions, then it might be preferable to collect fewer samples at more sites. Generally speaking, though, it is better to produce highly reliable results at fewer sites than less reliable results at many sites. Other potential strategies to reduce monitoring costs include the following:

- A phased approach wherein subsets of the overall study are addressed sequentially and the study stopped when sufficient data are collected.
- Limiting the number of constituents evaluated instead of reducing the number of storm events monitored.
- Using available data from published sources to supplement the study, thereby reducing the data collection effort. (Unfortunately, this is rarely possible.)

After each modification of the study scope, the key question that needs to be answered is: "Will the current Study Plan provide the information needed to reliably answer the study questions?" If the answer is "no," then the study scope needs to be revisited. If the budget will not allow the experimental work needed to answer the study questions, then perhaps the study questions themselves can be revised. If even that approach does not work, then the possibility of postponing the study until adequate resources are available should be considered. It makes little sense to undertake a study that will not answer the study questions.

2.1.6.4 Other Cost Reduction Strategies

As desctibed above, the Study Plan should include a cost estimate to design, construct, monitor and report the study findings. This estimate should be compared with the available budget. If the available budget is insufficient to complete the study as initially designed, then cost reduction strategies will need to be considered. In lieu of changing the scope of the monitoring, there are other cost reduction strategies for BMP pilot studies as discussed below:

1. Integrate stormwater BMP pilot projects with larger construction projects. This strategy applies to both retrofits and new construction, and offers a variety of benefits, including:
   - More opportunities to locate BMPs in conjunction with other features (e.g., drainage systems, interchanges);
   - Giving engineering staff experience with respect to stormwater BMP design, construction, operation, and maintenance;
   - Reduced mobilization, traffic-control, and equipment costs, as well as economies of scale during the construction process; and
   - Regulatory compliance cost savings through the use of single permits for the entire project.
2. Create cost savings and water quality improvements by choosing cross-jurisdictional partnerships within watersheds. Cost sharing and cooperation between Caltrans and other agencies in constructing joint stormwater evaluation facilities should result in greater cost-effectiveness.
3. Consider small-scale testing in initial stages when the BMP is not well defined. This allows many approaches to be tested more quickly and cost effectively than full-scale pilots. With this approach, researchers can discard concepts that do not have merit before the expense of full-scale pilots.

The optimization described above is part of study planning, but does not need to be a specific section in the Study Plan TM that documents the planning steps. However, trade-offs that had to be made in response to project constraints should be documented where appropriate. For example, 20 sites might be statistically best, but if only three were chosen for budget reasons, that should be made clear in the Study Plan TM.

2.1.6.5 Study Plan Validation

After the Study Plan has been optimized, it is important to validate that it will yield results that answer the study questions. The proposed study questions should be listed and the corresponding components of the Study Plan described and cross-referenced. The key question that needs to be answered is: “Will the current Study Plan provide the information needed to reliably answer the study questions?” If the answer is “no,” then the study scope needs to be revisited.

As an example, consider the study question “What is the maintenance frequency for the filters?” To confirm that it will be possible to answer this study question, one can discuss how the Study Plan specifically required collection of water level data (head) to give an indication of clogging of the filter media.

Examples from the Files ....

Study Plan Validation for the Study of Alternative Filter Media and Outlet Control Devices

The purpose of this study is to improve the performance of partial Austin sand filters by testing alternative filter media and evaluating the impact of outlet controls and increased drain time. Below is validation for the Study Plan:

Study Question	How Study Plan Addresses the Study Question
Approval Questions	
How does effectiveness vary for various pollutants of concern?	Automated sampling will be conducted to determine the impact of changes in drain time and filter media on treatment performance for the targeted pollutants. At minimum, composite influent and effluent water quality data will be collected for TSS, turbidity, nutrients (total and dissolved phosphorus, TKN and total nitrogen), and total and dissolved metals (Pb, Cu, Ni, Cr). Statistical analyses will include effluent probability method analysis and tests for significant differences between influent and effluent concentrations.
How does performance of the improved partial Austin filters compare to other currently approved BMPs that target the same constituents?	The study data (e.g. constituent removal, BMP operating conditions, maintenance requirements, and costs) collected during the monitoring period will be compared to existing data for Austin sand filters and other currently approved BMPs. Statistical analyses will include comparisons of effluent concentrations and ANOVA analysis for the key constituents of concern.
Will the operation of the BMP produce significant adverse environmental impacts?	Any undesirable affects observed during the monitoring period will be documented. In addition to effluent turbidity, the Study Plan recommends measurements for pH and sampling for selected metals that could potentially be leached from the media. Assessment of adverse effluent quality effects will be evaluated by tests for significant differences between influent and effluent concentrations or levels.
What are the maintenance requirements for the improved Austin filters?	Anticipated maintenance activities, based on those established for Austin sand filters, are listed in Section 1.5 of the Study Plan. All maintenance work including unanticipated activities will be documented during the monitoring period. Labor and material costs will be documented. Maintenance requirements will be compared to requirements for approved Austin sand filters.
What are the life cycle costs for the improved Austin filters?	BMP design, construction, operation, and maintenance costs will be collected during the period of this pilot study for the life cycle cost analysis. These costs will be compared to those for approved Austin sand filters.
Optimization Questions	
How does effectiveness vary with various types of media?	This Study Plan is designed to compare performance of the Austin filters with various types of media under similar influent concentrations or loads. A minimum of two Austin filters is recommended in a selected location, and influent flow will be split equally to each filter. Treatment data collected for each media type tested will provide comparison between these media. Statistical analyses will include ANOVA analysis for the key constituents of concern.
What impact does the filter media have on the maintenance cycle?	Anticipated maintenance activities, based on those established for Austin sand filters, are listed in Section 1.5 of the Study Plan. The maintenance requirements of the alternative media filters will be documented, and at the end of the study these maintenance requirements will be compared to each other and to those for standard Austin sand filters.
Do these filters perform hydraulically similar to Austin sand filters?	The hydraulic performance of the filters will be determined by measuring water level changes above the surface of the media in the filtration chamber. The change in hydraulic conductivity will be estimated over time. This data will be compared to hydraulic data available for Austin sand filters.

2.1.7 Step 7: Document the Study Plan

Once the Study Plan is complete, it is vitally important to properly document it, along with the operational requirements and procedures associated with implementing it, in a Study Plan TM. An example outline for a Study Plan TM is provided in Appendix B.

Documented Study Plans will greatly assist the PDT in ensuring that the overall validity of the study is maintained in the face of unavoidable deviations from the original plan that occur during the execution of the study. Additionally, the documentation will serve as a valuable resource for data quality assessment activities and for making a final determination of whether the collected data achieved the performance or acceptance criteria.

Early documentation of the Study Plan will also improve the efficiency and effectiveness of later stages of the data collection and analysis process, such as the development of field sampling procedures, QC procedures, and statistical techniques for data analysis. Another valuable aspect of documentation is to ensure that the statistical assumptions that underlie the study are not violated by practical activities.

Finally, the written Study Plan will inform all parties involved about the goals, methods, and decisions made in formulating the study. For various reasons, the parties constructing or monitoring the pilot facilities may not be the same as those who planned the study. Individuals may move on and off the PDT over time. If the pilot facilities are constructed as part of an ongoing project, the Resident Engineer and contractor will not have participants in the study planning. For a multi-year study, the PDT itself might change as contract terms expire. A well-documented Study Plan will serve to assure that the execution of the experimental work is consistent with the study goals.

Documentation of the Study Plan should also include pilot study scheduling and associated cost estimates. The PDT should establish a general timeline for the pilot study. Benchmarks, including site selection; environmental approvals; permitting; Plans, Specifications, and Estimate (PS&E) package preparation; construction; submittal of the Operations, Maintenance and Monitoring (OM&M) Plan; monitoring plan implementation; submittal of the Interim Report(s) (if required); and submittal of the Final Report, should be identified within the schedule. Cost estimates should be developed for site selection, environmental approvals, permitting, PS&E package preparation, construction, preparation of the OM&M Plan, monitoring, inspection and maintenance, submittal of the Interim Report(s) (if required), and the submittal of Final Report.

2.1.8 Study Planning Summary

Table 2.4 provides a checklist that can be used to validate the proposed study in relation to the problem and other Caltrans needs.

Table 2.4 Study Planning Summary

Step 1 Describe the Problem	1. Describe the problem or need that inspires the study. 2. Specify how the pilot study will help the Department solve the problem or fill the need.
Step 2 Define the Study Goals	1. Review available background information. 2. Describe the BMP and its unit processes. 3. Formulate study questions. 4. Describe key assumptions that have the potential to influence the study outcome.
Step 3 Specify Study Type	1. Select the study type (monitoring approach) based on: • Study questions • Type of BMP • Study constraints • Current and historic conditions of the study area
Step 4 Identify Study Variables	1. Identify the types of data to be collected in the study to answer the study questions. 2. Identify variables that may affect the data based on consideration of site characteristics, BMP characteristics, storm characteristics, and maintenance practices. 3. Check assumptions to assure important variables are not being ignored.
Step 5 Specify Study Methodology	1. Specify which study variables are to be fixed, which ones will be constrained or controlled, and which ones will be monitored. 2. Specify site selection parameters. 3. Specify BMP physical characteristics and operational procedures. 4. Determine the length of the study period and the number of BMPs to be monitored to achieve the desired level of statistical confidence. 5. Specify the data collection and analytical methods.
Step 6 Optimize and Validate the Study Plan	1. Specify the available budget to perform the study. Review the proposed plan and determine whether any changes are needed because the study assumptions have changed or to accommodate the proposed budget. 2. Review the Study Plan in light of the original objectives and changes as needed.
Step 7 Document the Study Plan	1. Compile information generated in previous six steps. 2. Identify project constraints. 3. Review information to identify alternative sampling and analysis designs. 4. Select and document a Study Plan that will yield data that will best meet performance criteria.

Chapter 3 Project Site Selection

During the site selection phase, the study objectives developed during the Study Plan processes are utilized to select the necessary number of pilot sites identified in the Study Plan TM. The site selection process is presented in Figure 3-1 and is composed of four primary steps: siting criteria development; data collection and analysis; site evaluation; and analysis and reporting. Tasks in which District NPDES Coordinator involvement is recommended are identified with an "*". This chapter presents the procedures and guidelines for performing each step.

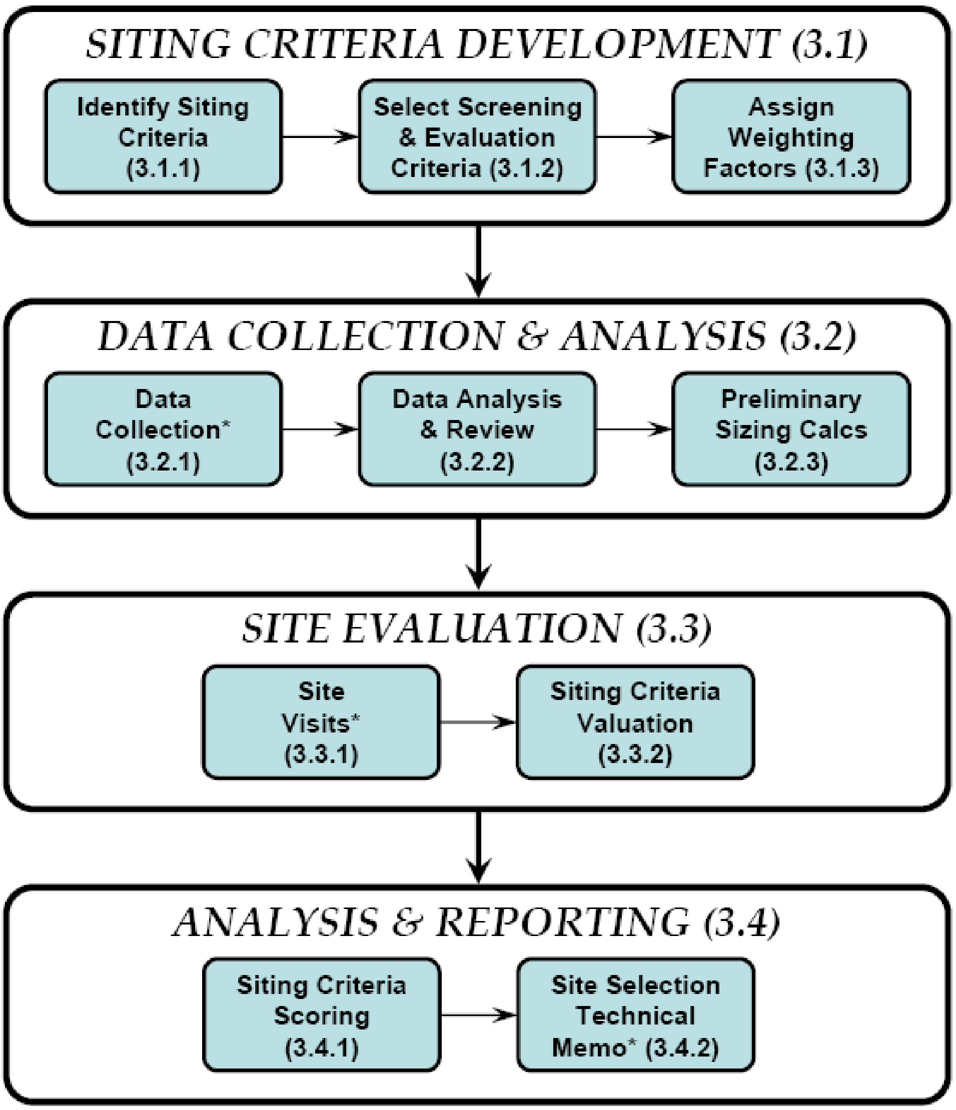


Figure 3-1 Site Selection Process Flowchart

3.1 Siting Criteria Development

Utilizing the pilot study objectives, siting criteria, and key parameters documented in the Study Plan TM, along with any pilot BMP design criteria established after completion of the Study Plan TM, a list of site characteristics (i.e., siting criteria) is prepared to evaluate and compare candidate sites. This activity encompasses three tasks: identification of appropriate siting criteria; identification of screening versus evaluation criteria; and assignment of weighting factors.

3.1.1 Siting Criteria Selection

Depending on the specific objectives and pilot BMP under evaluation, the list of desired site characteristics may include as many as 20 criteria. When developing the list, it is important to use selection criteria that are quantifiable in nature to avoid subjective evaluation and facilitate comparison of candidate sites. For example, the criterion "Available Hydraulic Head" would be better than "Minimum Hydraulic Head Met?" because the former would allow differentiation between sites that met the minimum hydraulic head requirement. Functionally dependent selection criteria should also be avoided to preclude double-counting bias in the results. For example, "Hydrologic Soil Group (A, B, C, D)" and "Soil Infiltrate Rate" would not be used because the two criteria are not mutually exclusive (hydrologic soil groups A and B imply a higher infiltration rate than hydrologic soil groups C and D).

For purposes of pilot studies, site selection criteria may be divided into three categories: BMP design requirements, monitoring requirements, and other siting constraints. Each of these categories is discussed in the following sections. Additional information on site selection considerations is provided in the Stormwater Quality Monitoring Protocols (Caltrans 2003a).

3.1.1.1 Pilot Design Requirements

BMP design criteria are characteristics that are necessary for the successful operation of the pilot facility. Actual criteria used will depend on the technology being tested, but the more common ones include:

- Drainage area, for pilot devices that are designed for a specific range of tributary drainage areas (such as a Multi-Chamber Treatment Trains, which are typically designed for drainage areas no more than 2.5 acres, or 1 hectare, in size).
- Hydraulic head, for devices that require a minimum amount of head to operate by gravity (such as the Inclined Screen Gross Solids Removal Device which requires at least 5.5 feet [1.68 m] of hydraulic head). In addition to the head needed for the BMP itself, certain flow

measuring devices (e.g., H-Flumes) are not designed to operate under submerged conditions and require additional hydraulic head to ensure no backwater conditions within the device.

- Water Quality Volume (WQV) for volume-based devices. Pilot study objectives might require a minimum WQV for cost-effectiveness (current Caltrans policy specifies a minimum WQV of 0.1 acre-feet [123 cubic meters] for many approved BMPs and a maximum WQV to ensure projects budgets are not exceeded).
- Water Quality Flow (WQF) for flow-based devices. Pilot study objectives might require either a minimum and/or maximum WQF to ensure the site is representative of conditions that would be encountered under a full implementation.
- Power availability, for devices that require electrical power to operate specific components (such as some Chemically Enhanced Detention Basins that require electrical power to operate the chemical dosing systems).
- Soil classification, for those pilots that incorporate infiltration as a removal mechanism and require a certain soil classification (such as Infiltration Trenches which require Hydrologic Soil Group Type “A” or “B” soils).
- Soil percolation rates, for those pilots that incorporate infiltration as a removal mechanism and require a minimum (or maximum) infiltration rate (such as Infiltration Basins which require an infiltration rate between 0.5 inches [12.5 mm] per hour and 2.5 inches [60 mm] per hour).
- Site geometry, for devices that require specific shapes (e.g., length to width ratios) for optimal performance (such as Detention Basin devices for which rectangular shaped basins are preferred over square shaped basins).
- Space, based on preliminary hydrologic/hydraulic and sizing calculations (such as Concrete Vault Austin Sand Filters which require at least 36 feet by 84 feet of space for 10,000 cubic feet of WQV). This is different from site geometry, in that a site may have adequate overall space but not be in the desired shape. Apart from the space required for the BMP itself, the site must have adequate room for all monitoring equipment (e.g., flumes, samplers, enclosures, etc.). More importantly, sufficient distance must be available upstream of certain flow measuring devices (e.g., some flumes require the influent flow in-line with the flume for a length equivalent to 12 times the pipe diameter) to establish uniform flow conditions if these conditions do not already exist.
- Depth to groundwater. A minimum depth to the seasonally high groundwater table is typically required for some BMPs (such as infiltration devices), and preferred for all BMPs to avoid construction cost escalations (dewatering, structure anti-buoyancy, etc.).
- Traffic, in the event that the pilot needs to be located in an area with specific Annual Average Daily Traffic (AADT) requirements.

- Stormwater sources. Typically, sites are preferred where the majority of the runoff is wet weather runoff from impervious (paved) Caltrans right-of-way. Sites with significant dry weather flows, significant non-Caltrans runoff, or significant runoff from pervious areas should be avoided. Caltrans representative runoff should be high in:
  - Urban areas because of the potential for unknown sources;
  - Areas with highly erodible soils surrounding the pilot sites; and
  - Studies where a comparison to effluent limits is required.

3.1.1.2 Monitoring Requirements

Monitoring requirements are characteristics necessary for the successful monitoring of the pilot BMP under evaluation. These typically include:

- Number of inlet pipes/streams. Monitoring pilot performance requires accurate characterization of the runoff discharging into the device (i.e., before-treatment), and a single inlet stream is preferred. Sites with multiple inlet streams either require costly drainage modifications to combine multiple streams or costly monitoring programs to accurately characterize the influent runoff.

> *Examples from the Files ....*
>
> Although the existing Compost Stormwater Filter BMP at Route 73 and Newport Cost Drive had multiple inlet pipes, it was selected as a retrofit site for one of the Route 73 Detention Basin with Overflow BMP pilots due to its other characteristics and proximity to other pilot sites.

- Proximity to next closest or paired site. As part of an "Influent and Effluent" study, if one of the pilot study objectives is to compare the performance of a device at multiple sites with similar runoff characteristics, then it is typically preferred to have the sites close together such that the runoff at each site may be considered similar. As part of a paired watersheds study, the distance between the paired sites is important to facilitate monitoring activities.

3.1.1.3 Safety Requirements

Safety requirements are characteristics necessary for the safety of the PDT and the public. When evaluating these characteristics, coordination with the District traffic operations unit should be performed, either directly or by the District NDPES Coordinator. Such communications must be documented and shared with the Department Task Manager. Safety issues typically include:

- Distance to Edge of Traveled Way. Caltrans policy requires that roadways include a traversable clear recovery area to provide a clear recovery zone (CRZ) for vehicles that have left the traveled way. Obstacles located in the recovery zone should be removed, relocated, or shielded (e.g., with guardrail or crash cushions). The minimum recovery area is 30 feet (9

m) for freeways and high-speed (greater than 43.5 mph [70 km/hr]) expressways, and at least 20 feet (6 m) for conventional highways. Pilot project components that would be considered an obstacle include flumes, sampler enclosures, and any above-grade concrete structure. Selecting sites with sufficient space to locate the pilot BMP outside the recovery zone will avoid the costly shielding of the BMP (design and construction) and the additional coordination with Traffic Safety. Additional information on this issue may be found in Chapter 7 (Traffic Safety Systems) of the Caltrans Traffic Manual, at www.dot.ca.gov/hq/traffops/signtech/signdel/trafficmanual.htm.

- Access. The pilot site must be accessible to construction and monitoring personnel without risk of injury. Sites that have access from a non-Caltrans roadway are ideal, but are not usually possible. Sites at which the activities occur in roadway medians (i.e., between opposing lanes of traffic) are not safe and should be avoided.

3.1.1.4 Implementation Issues

In addition to site characteristics necessary for the design and monitoring of the pilot(s), there are a number of other characteristics that can have a direct impact on the project's ability to meet its objectives (primarily related to schedule and cost). These criteria are sometimes referred to as implementation issues or site constraints, and may include:

- Sufficient right-of-way – Acquisition of right-of-way is time consuming and costly, and should be avoided. Selection of sites with adequate right-of-way is critical to meeting project schedules and budgets.
- Baseflow – Candidate sites in which permanent sources of runoff (baseflow) exist may or may not be desirable depending on the pilot device being tested. For example, a baseflow would be desirable for wet basins, but not for a device which is designed to be dry between storm events. Furthermore, baseflow may have an undesirable impact on monitoring as the flow being recorded reflects more than just the storm event.
- Conflicts with high risk utilities – In accordance with current Caltrans policy, high risk utilities are utilities conducting petroleum products, oxygen, chlorine, toxic or flammable

Cost Reduction Strategies $

✓ Perform site selection and assessment activities to avoid hidden costs associated with obstructions such as utility conflicts and buried objects.

Examples from the Files ....

Site Selection for the District 3 Chemically Enhanced Detention Basin BMP Pilot Project included the evaluation of 26 candidate sites. Although one of the sites had the highest overall score, it was rejected from future consideration because it had a potential conflict with a high risk utility.

gases, natural gas in pipelines greater than 6 inches in diameter, and electric supply lines with a potential to ground of more than 300 volts without effectively grounded shields (see PDPM, Appendix LL, at www.dot.ca.gov/hq/oppd/pdpm/pdpmn.htm). Selection of sites with high risk utilities present should be avoided if possible as they require utility coordination and relocation/adjustment/protection, impacting both schedule and budget.

- Conflicts with low risk utilities – Low risk utilities are utilities conducting natural gas in pipelines 6 inches and less in diameter, and electric supply lines with a potential to ground of more than 300 volts with effectively grounded shields. Although not as critical as high risk utilities, conflicts with low risk utilities will result in utility coordination and relocation/adjustment/protection, and should be avoided if possible.
- Environmental issues – Pilot study projects with environmental impacts (to waterways, biological, cultural, and other protected resources) will require agency coordination and may not qualify for a Categorical Exemption (CE) (under the California Environmental Quality Act [CEQA]) or Categorical Exclusion (under the National Environmental Policy Act [NEPA]). If this is the case, Environmental Documents (EDs) (e.g., Environmental Impact Reports [EIRs], Environmental Assessments [EAs], Environmental Impact Statements [EISs]) would be required prior to project approval, significantly delaying the project schedule (by one year or more). It is strongly encouraged that sites with environmental issues be eliminated from consideration.
- Line of Sight Visibility – Depending on the area in question and the BMP, visibility of the BMP from nearby residential areas or recreation areas may be a concern. The distance from the nearest visual receptacle to the site may be used as a method for assessing this criterion.
- Conflicts with other construction – Unless it is desired to construct the pilot project under the Contract Change Order (CCO) Delivery Method, sites with either ongoing or proposed (within the pilot project schedule) construction should be avoided. Caltrans maintains a list of Caltrans Ongoing Contracts (available on the Construction website at www.dot.ca.gov/hq/construc/statement.html) that should be consulted to determine if there is any other ongoing work in the area. Consultation with the local District NPDES Coordinator is also recommended to identify future projects in the area.
- Completeness of Data – Some sites may have sufficient data to proceed directly into design, while others may require additional information to be collected.

3.1.2 Screening vs. Evaluation Criteria

Once the list of siting criteria has been established, the next step is to identify which criteria shall be used for site screening and which shall be used for site evaluation. Screening criteria are used as an initial screening tool to determine if a site has a specific characteristic that should automatically preclude it from serving as a pilot site (i.e., fatal flaw). Evaluation criteria are then used to compare candidate sites that passed the screening criteria. This approach is valuable when there are a large number of candidate sites and the schedule/budget does not allow a detailed evaluation of all sites.

Screening criteria may be any of the three types of criteria described above. For example, if the pilot BMP under evaluation requires 3 feet (900 mm) of hydraulic head to function by gravity, and one of the candidate sites has a maximum available hydraulic head of 1 foot (300 mm), the site would be considered unsuitable. Or, if one of the candidate sites does not have enough space for the BMP and requires acquisition of additional right-of-way, it might be rejected. Or, if one of the candidate sites is in the middle of protected Coastal Sage Scrub habitat, the site might be eliminated from further consideration due to the environmental impact and necessary agency coordination. Table 3.1 presents an example list of siting criteria which may be used for screening purposes. For each criterion, the desired value that would result in the candidate site passing the screening phase is given.

Table 3.1 Example Screening Criteria for Site Selection

Screening Criterion	Desired Value	Passing Value
Sufficient Hydraulic Head	4 ft	Yes
Sufficient Water Quality Volume	5000 cu-ft	Yes
Sufficient Right-of-Way	20 ft	Yes
No Conflicts with Other Construction	Yes	Yes
No Environmental Issues	Yes	Yes
No High-Risk Utility Conflicts	Yes	Yes
Sufficient Soil Infiltration Rates	1 in/hr	Yes
Sufficient Depth to Groundwater	10 ft	Yes

As presented in Table 3.1, in order to facilitate the analysis and comparison of screening criteria, all criteria should be worded such that the same response (either “Yes” or “No”) represents the same meaning throughout. With this approach, interpretation of the results is more straightforward (e.g., any “No” in the table above indicates that the site did not pass the screening criteria).

Note that some siting criteria may be used for both screening and evaluation. For example, hydraulic head may be used as a screening criteria if the BMP requires a certain amount of head to operate by gravity, and it may also be used as an evaluation criteria to differentiate sites that passed the screening criteria (e.g., sites with more hydraulic head are scored higher than sites with less hydraulic head).

3.1.3 Weighting Factors for Evaluation Criteria

When reviewing the final list of evaluation siting criteria, it quickly becomes apparent that some criteria might be considered more important to the overall program objectives than others. For example, knowing how much hydraulic head there is to work with is more important than knowing if the site will encroach upon the recovery zone. Or, having a site with high risk utilities is more important to the project (from an impact perspective) than having a site with low-risk utilities present.

To account for and control the relative importance of evaluation siting criteria, a weighting factor is assigned to each. The higher the weighting factor the more important the criteria. However, care should be used when assigning a weighting factor to an evaluation criterion, which was also used as a screening criterion. This is because once a site has passed the screening phase, the screening criteria may not be as important as other criteria not yet evaluated. For example, available head is often used as a screening criterion because certain BMPs have a minimum head requirement. If a specific site meets that minimum requirement, the actual amount of available head may not significantly influence the ranking of the site. In that case, the hydraulic head evaluation criterion would be given a lower weighting factor.

Weighting factors to be utilized for pilot study siting activities are presented in Table 3.2. The actual assignment of weighting factors is somewhat subjective and may even be considered controversial. As a result, it is important to obtain Caltrans review and approval before scoring the evaluation siting criteria (see Section 3.4.1).

Table 3.2 Evaluation Siting Criteria Weighting Factors

Value	Relative Importance
1	Not Very Important
2	Somewhat Important
3	Important
4	Very Important

3.1.4 Criteria Development Example

Assume that a pilot study is being conducted in the Lake Tahoe area to evaluate the performance of detention basins enhanced by the addition of a chemical coagulant. Table 3.3 presents a list of the siting (screening and evaluation) criteria that may be established for the pilot study, and the weighting factors that may be used for the evaluation criteria. As noted above, some criteria may be used for both screening and evaluation purposes, such as hydraulic head, as shown in the table. Refer to Section 3.4.1 for assessing and scoring the evaluation criteria.

Table 3.3 Siting Criteria Development Example

Criterion	Screening	Evaluation	Weighting Factor
Right-of-Way	✓		
Conflicts w/ other construction	✓		
Agency Coordination Required	✓		
Impacts to High-Risk Utilities	✓		
Soil Classification	✓		
Hydraulic Head	✓	✓	2
Vegetation Type	✓	✓	2
Space for Dosing/Mixing		✓	4
Basin Capacity (Percent WQV)		✓	4
Percent Caltrans Runoff		✓	3
Design WQV		✓	3
No. of Inlet Pipes		✓	3
Distance to Paired Site		✓	3
Depth to Groundwater		✓	2
Impacts to Low-Risk Utilities		✓	2
Soil Percolation Rate		✓	2
Distance to Edge-of-Traveled Way		✓	1
Space for 4:1 Side Slopes		✓	1

3.2 Collection and Analysis of Existing Data

Once the siting criteria have been established, the information needed to evaluate the candidate sites is known and may be gathered/computed. This activity encompasses three individual tasks: data collection; data analysis and review; and preliminary sizing calculations.

3.2.1 Collection of Existing Data

Much of the information needed to evaluate the candidate sites already exists in one form or another. In some cases, there is more information available than what is actually needed. Performing data collection after the siting criteria have been established, therefore, ensures that resources focus their efforts on gathering only the information that is actually needed. Both Caltrans and non-Caltrans sources should be included in the data gathering activity as they serve different purposes and complement each other. Internal Caltrans documents may include:

- Roadway as-built drawings,
- Design drawings (for project areas under design),
- Drainage reports,
- Aerial photography,
- Storm drain outfall inventory database,
- Project initiation documents (e.g., PSR, SWDR, PEAR),

- Project approval documents (e.g., PR, SWDR),
- Environmental documents,
- Previous water quality / pilot study reports,
- Geotechnical report, and/or
- Ongoing contract reports.

During data gathering, District staff should be consulted to determine if there are any future planned projects in the area or if there is any additional information available. Non-Caltrans sources may include:

- Natural Resources Conservation Service (NRCS) soils data,
- U.S. Geological Survey topographic maps,
- National Weather Service precipitation data,
- U.S. Geological Survey stream gauge records,
- County land use maps,
- Previous water quality / pilot study reports,
- Literature on pilot BMP under evaluation,
- Public domain / proprietary aerial photography,
- Public domain / proprietary GIS data, and/or
- City Plan / General Plan / County Plan.

To assist with data collection, a checklist may be used to document and record the data gathering efforts. The checklist would list all candidate sites and all possible sources. Check marks would be placed next to each site under the corresponding source.

3.2.2 Analysis and Review of Existing Data

As the information is collected, it is important to perform a review of the data to make sure it is appropriate for the intended purpose. For example, the following questions might be asked:

- Is it complete (are there missing pages)?
- Is it missing data?
- Is it recent enough to be considered valid?
- Does it reference another document or source?
- Is the data consistent with other documents?

As a result of the review, it might be determined that the data is insufficient or incomplete, and additional data gathering is necessary.

3.2.3 Preliminary Sizing

Some of the siting criteria may not be explicitly reported in the gathered documents and must be computed (such as the WQV or WQF). For example, as-built drawings will show drainage layouts and profiles, roadway vertical alignments, roadway lengths, and embankment slopes, but will not show runoff time of concentrations, drainage areas, available hydraulic head, or right-of-way needs. Therefore, the appropriate information is extracted from the source documents to perform preliminary hydrologic and hydraulic calculations for each site. In addition, initial area (footprint) requirements may be estimated to assist with right-of-way assessments. If a candidate site is included in the Caltrans storm drain outfall inventory database, the drainage areas provided in the database may facilitate these calculations. However, the information in this database is not necessarily accurate (areas provided in the database were found to be off by as much as 100 percent in one of the Lake Tahoe pilot studies) and should be considered preliminary. If there is a concern regarding the information in the existing documentation, a basic topographic survey may be considered. In addition, the Caltrans Basin Sizer program may be used to estimate detention basin footprint requirements.

Depending on the number of candidate sites, it may not be economically feasible to perform preliminary sizing calculations on every site. Furthermore, depending on the established siting criteria, certain hydrology and hydraulic calculations may only be needed for site evaluation and not for site screening. Under these circumstances, it might be more appropriate to perform only those calculations that are necessary for screening and avoid expending resources on calculations for sites that would never make it past the screening phase. The decision whether or not preliminary sizing calculations need to be performed for all sites should be made in coordination with the Caltrans Task Order Manager.

3.3 Site Evaluation

The purpose of site evaluations and site visits is to confirm information gathered from the existing data collection task, gather additional site information, confirm space availability outside CRZ for BMP and monitoring equipment, and document the site photographically. This section presents some basic guidelines on conducting site visits and completing the site evaluations.

3.3.1 Site Visit Considerations

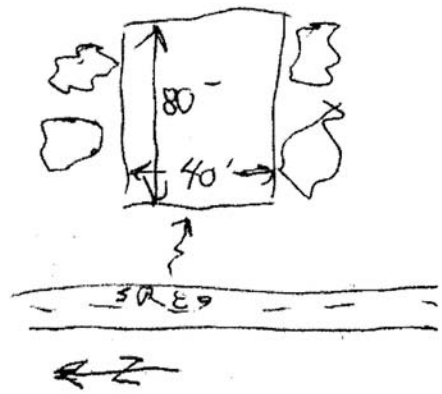
Performing site visits of candidate pilot sites should be planned out to use the time spent in the field cost-effectively and to conduct the visits in an efficient manner. Some basic considerations are:

- Safety first. The safety of the inspection team and traveling motorists is the number one priority when working within the right-of-way. All necessary precautions should be taken to ensure the safety of everyone.
- Get an Encroachment Permit (EP). If siting activities are conducted by either non-Caltrans staff or an A-E Consultant that is unable to use their contract as an EP (see Section 4.1.1), an EP is required. Although this is not necessary if a Caltrans employee is a member of the siting team, a permit should be obtained in case a Caltrans employee is unable to attend at the last minute and the siting cannot be delayed. The permit will specify any requirements the site visit team must comply with, such as parking restrictions and dress codes (hard hats, safety vests, and safety goggles must be worn at all times).
- Travel in pairs. Siting should never be conducted alone and at least two people should perform the site visits. This provides additional support for visual observations and data recording and ensures the safety of the individuals.
- Coordinate with District. It is necessary that the site visits be coordinated with District and/or HQ staff in the event they wish to participate. The evaluation team should include a representative from the District Environmental Branch to facilitate the identification of any potential environmental issues.
- Bring gathered information. Information gathered during the data collection and analysis phase should be brought to the site visits (especially maps, construction plans, and aerial photographs) to help guide the field evaluation and confirm documented information (in the event that it may not be recent).
- Fill out field form. The actual field form should be filled out while conducting the site visit. Taking notes on a separate piece of paper and transcribing them onto the field forms at a later time is not cost effective and leads to mistakes. A sample field form is presented in Figure 3-2. Note that this form is only an example, and should reflect the actual criteria developed for the project.
- Take photographs. Digital photographs should be taken of each site to record the conditions during the site visit. A photograph log should be maintained as each photograph is taken, recording the date, site location, and direction the camera is facing (use a compass if necessary). Trying to remember the next day which photograph goes with which site inevitably leads to mistakes.
- Review recorded data. Prior to departing from the site, review the data collected and photographs taken to avoid having to return to the site.
- Take Soil Samples. If soil analyses are required for design purposes (such as identifying concentrations of ADL or structural loading), consider taking the samples now but holding on to them until the analyses are actually needed.

Date: 6-9-04	**Surveyed by:** J. Ruesga
District: 3	**Location:** SR 89 PM 25.13

Screening Criteria	
Sufficient ROW (Y/N)	N
Other ongoing/planned construction (Y/N)	N
Environmental agency coordination (Y/N)	Y
High Risk Utilities (Y/N)	N
Existence of dry weather flow (Y/N)	N
Available Hydraulic Head (m)	3.4
Space for dosing/monitoring/mixing (m)	>10
Basin capacity (% WQV)	90
% of runoff from Caltrans roadways	100
Design WQV (m^3)	530
No. of inlet pipes	1
Distance to paired site (km)	5.3
Site geometry (L:W)	2:1
Evaluation Criteria	
Steepness of basin side slopes	<25%
Width of perimeter maintenance road	>4m
Steepness of basin access ramp	<15%
Depth to groundwater (m)	
Existing detention basin (Y/N)	N
Impacts to existing utilities (Y/N)	N
Distance to edge-of-travelled way (m)	>9
Distance to receiving water (km)	<1

Sketch:



Notes:

No existing DI
Site is currently public camping ground
No developed camp sites
Several large trees along edges
CT maint. could install DI on maint. contract

Figure 3-2 Sample Site Selection Field Form

3.3.2 Siting Criteria Evaluation

At this point, the values collected from the source documents and the data recorded on the field forms are entered into the Screening Criteria Matrix and Siting Criteria Evaluation Matrix. Although much of the information may have been gathered prior to the site visits, the matrices are not finalized until after the site visits to provide an opportunity to verify information. During this phase, only the "raw" values are entered and no ranking or comparison of candidate sites is performed. The purpose is only to record data collected from gathered documents and site visits.

Although the Screening Criteria Matrix is filled out for all candidate sites, the Siting Criteria Evaluation Matrix may not be. If there are not that many candidate sites, or if there are sufficient resources available, the evaluation matrix should be filled out completely, regardless of whether or not a specific site met the initial screening criteria. This is advantageous in the event that the final scoring results in too few approved sites and reconsideration of sites that did not satisfy the initial screening criteria is warranted. On the other hand, if resources are limited, it may be more beneficial to only fill out the evaluation matrix for sites that passed the screening criteria. Then, if not enough sites received final approval, the sites that did not pass the screening may be re-visited. The Caltrans Task Order Manager should be consulted regarding which approach is taken and the need to fill out the Siting Criteria Evaluation Matrix for all candidate sites.

An example Screening Criteria Matrix for the example siting criteria presented in Section 3.1.4 is presented in Figure 3-3, and a corresponding example Siting Criteria Evaluation Matrix is presented in Figure 3-4.

General Information and Location				Screening Criteria				
Site ID	County	Route	PM	Need Right of Way?	Conflict with Other Construction?	Agency Coordination Required?	Impact to High-Risk Utilities?	Insufficient Hydraulic Head?
7	Placer	267	7.35	NO	NO	NO	NO	NO
8	Placer	267	7.50	NO	NO	NO	NO	NO
9	Placer	267	7.61	NO	NO	NO	NO	NO
10	Placer	267	7.73	NO	NO	NO	NO	NO
11	Placer	267	7.84	NO	NO	NO	NO	NO
12	Placer	267	8.03	NO	NO	NO	NO	NO
13	Placer	267	8.14	NO	NO	NO	YES	YES
14	Placer	267	8.36	NO	NO	NO	YES	NO
15	Placer	28	3.23	NO	NO	NO	NO	NO
16	Placer	28	3.47	NO	NO	NO	NO	NO
17	Placer	89	0.91	YES	NO	YES	NO	YES
18	El Dorado	89	1.84	YES	NO	YES	NO	NO
19	El Dorado	89	2.59	NO	NO	YES	NO	NO
20	El Dorado	89	3.00	NO	NO	YES	NO	NO
21	El Dorado	89	3.04	NO	NO	YES	NO	NO
22	El Dorado	89	4.49	NO	NO	YES	NO	NO
23	El Dorado	89	18.40	YES	NO	YES	NO	NO
24	El Dorado	89	20.37	YES	NO	YES	NO	NO
25	El Dorado	89	25.13	YES	NO	YES	NO	NO
26	El Dorado	50	67.91	YES	NO	YES	NO	NO

Figure 3-3 Example Screening Criteria Matrix

Site Location				Siting Criteria Valuation										
Site ID	County	Route	PM	Hydraulic Head (m)	Space for Dosing/ Monitoring/ Mixing (m)	Basin Capacity (%WQV) (%)	Caltrans % of Runoff (%)	Design WQV (m^3)	No. of Inlet Pipes -	Distance to Paired Site (km)	Depth to Seasonally High Groundwater (m)	Impacted Low-Risk Utilities -	Distance to Edge of Traveled Way (m)	Space for 4:1 Side Slopes -
7	Placer	267	7.35	3.4	> 6	200%	100%	100	2	0.2	> 3	NO	> 9	NO
8	Placer	267	7.50	3.4	> 6	100%	100%	160	1	0.2	> 3	NO	> 9	MAYBE
9	Placer	267	7.61	3.4	> 6	190%	100%	140	1	0.2	> 3	NO	> 9	MAYBE
10	Placer	267	7.73	3.4	> 6	140%	100%	120	1	0.2	> 3	NO	> 9	MAYBE
11	Placer	267	7.84	3.4	> 6	290%	100%	50	2	0.3	> 3	NO	> 9	MAYBE
12	Placer	267	8.03	3.0	> 6	140%	100%	200	1	0.2	> 3	NO	> 9	MAYBE
13	Placer	267	8.14	1.8	> 6	50%	100%	110	1	0.4	> 3	NO	< 9	MAYBE
14	Placer	267	8.36	3.4	> 6	160%	100%	190	1	0.4	> 3	NO	> 9	MAYBE
15	Placer	28	3.23	3.4	> 6	380%	100%	80	1	0.4	> 3	NO	< 9	MAYBE
16	Placer	28	3.47	3.4	> 6	80%	100%	390	1	0.4	> 3	NO	< 9	MAYBE
17	Placer	89	0.91	1.8	> 6	180%	100%	170	1	5.3	> 3	YES	> 9	YES
18	El Dorado	89	1.84	3.4	> 6	150%	100%	170	1	1.2	> 3	YES	> 9	YES
19	El Dorado	89	2.59	3.4	> 6	100%	100%	150	1	0.7	> 3	YES	> 9	YES
20	El Dorado	89	3.00	3.4	> 6	210%	> 60%	140	1	0.1	> 3	YES	> 9	YES
21	El Dorado	89	3.04	3.4	> 6	210%	> 60%	120	1	0.1	> 3	YES	> 9	YES
22	El Dorado	89	4.49	3.4	> 6	310%	100%	80	1	2.3	> 3	YES	> 9	YES
23	El Dorado	89	18.40	2.4	> 6	500%	> 60%	30	1	3.2	> 3	YES	> 9	YES
24	El Dorado	89	20.37	3.4	> 6	1500%	100%	30	1	3.2	> 3	YES	> 9	YES
25	El Dorado	89	25.13	3.0	> 6	90%	100%	530	1	5.3	> 3	YES	> 9	YES
26	El Dorado	50	67.91	4.6	> 6	200%	100%	620	1	10.9	> 3	YES	> 9	YES

Figure 3-4 Example Siting Criteria Evaluation Matrix

3.4 Analysis and Reporting

The final phase of project site selection is the analysis of the data to determine the most appropriate site(s) and the preparation of a TM to document the work performed.

3.4.1 Siting Criteria Scoring

Each site is given a total score based on the results of the selection criteria evaluation in order to compare the candidate sites against one another in an objective manner and to assure that any favored sites are not selected. The score for each site is computed by adding up the individual scores for each selection criterion. The individual scores for each criterion are computed by multiplying the criterion's weighting factor by a normalized value. Given that the raw values for the selection criteria are in different formats (numbers, percentages, text), they must first be converted into a normalized value to ensure consistency and equality in the analysis. Table 3.4 presents the normalized values to be used and the corresponding definition.

Table 3.4 Pilot Study Siting Normalized Values

VALUE	DESCRIPTION
0	Unacceptable
1	Poor
2	Fair
3	Good
4	Excellent

To convert raw values into normalized values, a conversion chart needs to be established for each selection criterion. The chart should be developed taking into consideration the preferred (desired) value, values that would be considered undesirable, and the range of possible values. A number of different types of conversion charts are possible.

For example, for selection criteria with numeric values, each normalized value may correspond to a specific range of raw values. If "Hydraulic Head" is a criterion, and a minimum value of 900 mm (3 feet) is required, the following conversion chart might be used:

Raw Value (ft)	Normalized Value
< 3.0	0
3.0 – 3.5	1
3.5 – 4.0	3
> 4.0	4

The mapping in the above example is somewhat arbitrary and may vary based on the specific needs of the project. One approach to standardizing conversion of numeric values would be to map each normalized value to a percentage of the desired or required value. For example:

Percent Desired Value	Normalized Value
< 50%	0
50-75%	1
75-100%	2
100-125%	3
> 125%	4

Using the hydraulic head example, a raw value greater than 3.75 feet (125 percent of 3) would convert to a normalized value of 4, and a raw value less than 1.5 feet (50 percent of 3) would convert to a normalized value of 0. This approach is recommended only when there is not sufficient justification to use the previous approach.

For criteria in which the possible raw values are "Yes" or "No," and "Yes" represents the undesired value (as in the case of the criterion "Impacts to Low-Risk Utilities"), the following mapping is suggested:

Value	Normalized Value
Yes	1
No	3

For some selection criteria, the mapping may resemble a bell curve where too high of a value may be considered as undesirable as too low a value. For example, if "WQV" is a criterion, and minimum value of 100 cubic meters is desired, the following mapping might be used:

WQV (m^3)	Normalized Value
< 40	0
40-60	1
60-80	2
80-100	3
100 - 200	4
200-300	3
300-350	2
350-400	1
> 400	0

The actual method utilized to convert raw values into normalized values is not critical, as it can easily be considered subjective or controversial. What is important is that a logical process is used and the process is documented (in a Siting Criteria Normalization Matrix) such that it can be reviewed, revised, and approved. An example matrix for the previously developed example is presented in Figure 3-5.

Evaluation Criteria	**Normalized Value**				
	0	1	2	3	4
Hydraulic Head (m)	< 2.1	2.1 - 2.2	2.2 - 2.3	2.3 - 3.0	> 3.0
Space for Dosing/ Monitoring/ Mixing (m)	< 4.9	4.9 - 5.1	5.1 - 5.3	5.3 - 5.5	> 5.5
Basin Capacity (%WQV)	< 70	70 - 80	80 - 100	100 - 200	> 200
Caltrans % of Runoff	< 60	60 - 70	70 - 80	81 - 99	100
Design WQV (m3)	< 100 or > 400	100 - 110 or 350 - 400	110 - 123	123 - 180	180 - 350
No. of Inlet Pipes	> 3	3	2		1
Distance to Paired Site (km)	> 5.0	3.0 - 5.0	1.0 - 3.0	0.5 - 1.0	< 0.5
Depth to Seasonally High Groundwater (m)	< 2.0	2.0 - 2.5	2.5 - 3.0	3.0 - 4.0	> 4.0
Impacted Low-Risk Utilities	YES		MAYBE		NO
Distance to Edge of Traveled Way (m)	< 3.0	3.0 - 6.0	6.0 - 9.0	9.0 - 10.0	> 10.0
Space for 4:1 Side Slopes	NO		MAYBE		YES

Figure 3-5 Example Siting Criteria Normalization Matrix

After the raw values are converted into normalized values, scores for each candidate site may be computed. The results of the scoring are documented in the Siting Criteria Scoring Matrix. An example is presented in Figure 3-6. Note that the sites that did not pass the screening criteria are highlighted.

Site Location				Siting Criteria Scoring (Maximum Possible Score = 120)												
Site ID	County	Route	PM		Hydraulic Head	Space for Dosing/ Monitoring/ Mixing	Basin Capacity (%WQV)	Caltrans % of Runoff	Design WQV	No. of Inlet Pipes	Distance to Paired Site	Depth to Seasonally High Groundwater	Impacted Low-Risk Utilities	Distance to Edge of Traveled Way	Space for 4:1 Side Slopes	Total Score
				Weighting Factor	4	4	4	3	3	3	3	2	2	1	1	
7	Placer	267	7.35		4	4	4	4	1	2	4	3	4	3	0	**98**
8	Placer	267	7.50		4	4	3	4	3	4	4	3	0	3	2	**100**
9	Placer	267	7.61		4	4	3	4	3	4	4	3	4	3	2	**108**
10	Placer	267	7.73		4	4	3	4	2	4	4	3	4	3	2	**105**
11	Placer	267	7.84		4	4	4	4	0	2	4	3	4	3	2	**97**
12	Placer	267	8.03		3	4	3	4	4	4	4	3	4	3	2	**107**
13	Placer	267	8.14		0	4	0	4	2	4	4	3	4	3	2	**77**
14	Placer	267	8.36		4	4	3	4	4	4	4	3	4	3	2	**111**
15	Placer	28	3.23		4	4	4	4	0	4	4	3	4	3	2	**103**
16	Placer	28	3.47		4	4	2	4	1	4	4	3	4	3	2	**98**
17	Placer	89	0.91		0	4	3	4	3	4	0	3	0	3	4	**74**
18	El Dorado	89	1.84		4	4	3	4	3	4	2	3	0	3	4	**96**
19	El Dorado	89	2.59		4	4	3	4	3	4	3	3	0	3	4	**99**
20	El Dorado	89	3.00		4	4	4	1	3	4	4	3	0	3	4	**97**
21	El Dorado	89	3.04		4	4	4	1	2	4	4	3	0	3	4	**94**
22	El Dorado	89	4.49		4	4	4	4	0	4	2	3	0	3	4	**91**
23	El Dorado	89	18.40		3	4	4	1	0	4	1	3	0	3	4	**75**
24	El Dorado	89	20.37		4	4	4	4	0	4	1	3	0	3	4	**88**
25	El Dorado	89	25.13		3	4	2	4	0	4	0	3	0	3	4	**73**
26	El Dorado	50	67.91		4	4	4	4	0	4	0	3	0	3	4	**85**

Figure 3-6 Example Siting Criteria Scoring Matrix

3.4.2 Site Selection Technical Memorandum

The Site Selection TM documents the activities performed during site selection and the results obtained. The Site Selection TM should contain the following:

- Caltrans and non-Caltrans data collected
- District Coordination
- Candidate sites
- Screening selection criteria
- Evaluation selection criteria
- Evaluation selection criteria weighting factors
- Screening Criteria Matrix
- Siting Criteria Evaluation Matrix
- Siting Criteria Normalization Matrix
- Siting Criteria Scoring Matrix
- Conclusions
- Siting deviations that impact Study Plan
- Selected site limitations (for future monitoring)
- Field forms
- Site photographs

In addition to the above, the following supplementary information should be included for the selected site(s) to ensure consistency with the National Stormwater BMP Database:

- City
- Zip code
- Altitude to nearest 100 ft
- Watershed name
- Total watershed area
- Total percent impervious area in watershed
- Most relevant Regional Climate Station
- Land uses (for non-structural pilots)

The actual format of the Site Selection TM shall follow the outline provided in Appendix C.

3.5 Task Order Development

Unless directed otherwise by the Department Task Managers, task orders with pilot site selection activities should include, at a minimum, the following scope elements:

3.5.1 Kick-off Meeting

A kick-off meeting shall be held at the Department's Offices in Sacramento. The purpose of this meeting is to discuss the purpose, study questions, and approach for the project. In addition, potential locations or corridors of interest to the Department will be identified during this meeting. Meeting minutes shall be taken and distributed to all meeting participants.

- Deliverables:
  - Meeting Agenda
  - Meeting Minutes

3.5.2 Develop Siting Criteria

Appropriate site screening and evaluation criteria for the pilot study shall be developed, along with weighing factors. Siting and screening criteria shall follow the guidance in the approved Study Plan TM and the Caltrans Pilot Study Guidance Manual. A Draft set of Screening and Evaluation Criteria shall be submitted to the Department Task Manager for review and approval prior to initiating field activities.

- Deliverables:
  - Draft Siting Criteria
  - Final Siting Criteria

3.5.3 Develop List of Candidate Pilot Sites

A list of potential sites shall be identified through review of as-built plans and other information (for the locations or corridors of interest) and discussions with appropriate District staff. The PDT shall review the information available and request additional relevant information if the available information is insufficient to evaluate the sites at a pre-screening level.

- Deliverables:
  - List of Candidate Sites

3.5.4 Candidate Site Evaluations

Site visits of candidate pilot study sites shall be performed to complete the site evaluations and determine if specific sites need to be precluded because of site specific characteristics. A Site Selection Field Form shall be filled out for each site.

- Deliverables:
  - Site Selection Field Forms

3.5.5 Site Analysis and Reporting

Sites shall be scored in accordance with the approval Siting Criteria, and the siting matrices shall be completed. A Draft Site Selection TM shall be prepared and submitted to the Department Task Manager for distribution and review. The Draft Site Selection TM should include a lessons learned section. Refer to Section 8.4.4 for details. Following receipt of reviewer comments, a meeting shall be held in Sacramento to review the draft submittal and comments received. A Response to Comment Form shall be prepared with proposed responses to comments received, and submitted to the Department Task Manager for review. Following approval of the responses, a Final Site Selection TM shall be prepared and submitted.

- Deliverables:
  - Draft Site Selection TM
  - Draft TM Review Meeting Minutes
  - Draft TM Responses to Comments
  - Final Site Selection TM

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Chapter 4 Permits and Environmental Clearance

Following the successful planning and selection of sites for the pilot study, the collection of appropriate permits and environmental approvals should be initiated. Although final design documents (see Chapter 5) may be required to obtain final permits and approvals, the process should start prior to initiating design activities. Coordination with the appropriate District Environmental Branch at this stage will facilitate the permit/approval process and identify the level of design needed for various permits/approvals. This chapter presents the approval and permitting requirements with which pilot studies need to comply.

4.1 Permits, WBS 230.65

The permits that could potentially be required to conduct pilot studies are discussed below. These permits fall within two major categories: those issued by Caltrans; and those issued by other agencies.

4.1.1 Encroachment Permits

Execution of a pilot study involves field activities within the Caltrans right-of-way in almost every phase, including site selection, reconnaissance surveys, topographic surveys, construction, construction site inspections, operations, maintenance, and monitoring. In order to perform these activities, individuals other than Caltrans employees are required to obtain an Encroachment Permit (EP) from the local District. As defined in the Caltrans EPs Manual (Caltrans 2002b):

> *An* ***encroachment*** *is defined in the Streets and Highways Code as any tower, pole, pole line, pipe, pipeline, billboard, stand or building, or any structure, object of any kind or character not particularly mentioned in the section, or special event, which is in, under, or over any portion of the highway. "Special event" means any street festival, sidewalk sale, community-sponsored activity, or community-approved activity.*

An EP issued by Caltrans, therefore, provides the permittee the authority to enter the state highway right-of-way to construct approved facilities or conduct specified activities (Caltrans 2002b). It is not, however, a property right. EPs can be revoked by any departmental representative or law enforcement office if the permitted activity is deemed detrimental to the integrity of the state highway, or to the safety of the traveling public.

Typically, each activity requires a separate permit. However, at the discretion of the District Permit Engineer, a Permit Rider may be issued to amend an existing permit to cover additional subsequent activities (for example, an EP may be initially issued for site reconnaissance work, and then amended with a Permit Rider to include surveys and geotechnical investigations).

If the individual performing the activity is a Consultant working under an A-E State Contract, however, Caltrans has determined that the need for the Consultant to obtain a Caltrans EP does not always apply (Caltrans 2002a). As specified in the May 2002 Division of Procurement and Contracts Memorandum on Guidelines on the Issue of EPs for A-E Consultants, the executed A-E Contract serves as the EP for the A-E Consultants. The Consultant needs to carry the contract and pertinent task orders at all times while working within the right-of-way. Subconsultants and subcontractors are also exempt from EP requirements as long as the work they are performing is within the approved scope of work. If the work is unforeseen and outside the approved scope of work, the subconsultant or subcontractor must obtain an EP from the local District. The memo also specifies that under special circumstances, the Contract Manager may request an EP. Besides these provisions specified in the May 2002 Memorandum, the District may still require an EP for some or all pilot study activities (such as traffic control). Therefore, coordination with the Caltrans Task Order Manager and District Encroachment Permit Office is recommended during the Planning Phase to determine if an EP is necessary for any pilot study activities. If it is determined that a formal EP is not necessary and the Consultant will be using the A-E Contract as the EP, the respective District Encroachment Permit Office should be contacted to notify them that work will be performed in their District under an A-E Contract. Also, when performing work without a formal EP, the Consultant needs to carry the contract and pertinent task orders at all times while working within the right-of-way.

If it is determined that an EP is required, guidelines for preparing EP applications may be found at www.dot.ca.gov/hq/traffops/developserv/permits/.

It should be noted that the Environmental Division does not obtain encroachment permits. However, Caltrans Environmental is supposed to review EP applications to determine whether environmental studies are necessary.

4.1.2 Other Permits and Approvals

Federal, state (other than Caltrans), and local resource agencies often have vested interests in projects, which they protect by requiring mitigation of project effects, or by requiring various approvals, permits, or agreements. For the purposes of conducting pilot studies, these agencies typically include the U.S. Army Corps of Engineers (USACE), the U.S. Fish and Wildlife Service (USFWS), the California Department of Fish and Game (CDFG), the SWRCB, and the local Regional Water Quality Control Board (RWQCB). Other agencies, such as the California

Coastal Commission (CCC), the Tahoe Regional Planning Agency (TRPA), and the Bureau of Indian Affairs (BIA) may become involved depending on the project's location or other circumstances. It is essential that all possible permits and approvals be evaluated and obtained for a specific pilot study, as the respective agency can shut down the pilot study, or impose fines, for failure to secure the necessary permit, certification, and/or agreement.

Additional information on non-Caltrans permits may be found in the SER in Chapter 14 (Biology), Chapter 15 (Wetlands), and Chapter 18 (Coastal), at http://www.dot.ca.gov/ser/index.htm. Table 4.1 presents a summary of the non-Caltrans permits that may be required for a pilot study.

Table 4.1 Permit and Approval Requirements

Resource	Agency	Permit/Approval
Coastal Shoreline (except San Francisco Bay area)	Coastal Commission	Coastal Development Permit
Coastal Shoreline (San Francisco Bay area)	Bay Conservation and Development Commission	Coastal Development Permit
Lake Tahoe Watershed	Tahoe Regional Planning Agency	TRPA Project Permit
Stream Environment Zone	Tahoe Regional Planning Agency	TRPA Project Permit
Central Valley Floodways	Reclamation Board	Encroachment Permit
Water	U.S. Army Corps of Engineers	Section 404 Permit
	Regional Water Quality Control Board	Section 401 Water Quality Certification
	State Water Resources Control Board	NPDES Permit
Groundwater	Regional Water Quality Control Board	NPDES Permit
Fish and Wildlife Habitat, Threatened and/or Endangered Species	Dept. of Fish and Game	Section 1602 Streambed Alteration Agreement
	U.S. Fish and Wildlife Services and U.S. Forest Service	Biological Opinion
Cultural Issues	State Historic Preservation Office	National Historic Preservation Act Section 106 Programmatic Agreement Approval
	Advisory Council on Historic Preservation	National Historic Preservation Act Section 106 Programmatic Agreement Approval
	Native American Tribes	Consultation

The District's Environmental Branch is responsible for the implementation of Caltrans policies, programs, and procedures concerning environmental considerations, analysis, and compliance with environmental laws and regulations under CEQA and NEPA as well as other state and federal regulations. Identification of applicable permits/approvals for pilot studies conducted under the A-E Contract Delivery Method are the responsibility of the PDT in coordination with the District NPDES Coordinator and District Environmental staff. As a result, execution of pilot studies requires close coordination with District Environmental staff to determine project schedules; identify potential project issues, criteria, constraints, and impact mitigation; and ensure that all laws and regulations are followed during the course of project development and system testing.

The PDPM and SER identify necessary federal, state, and local permits and approvals based on three project criteria: project location, affected resources, and construction activities. This section presents the more common environmental permits and approvals for each criterion that may be required for a pilot study. Table 4.2 presents a list of possible pilot study activities that may require an environmental permit/approval. Coordination with the District NPDES Coordinator is recommended to identify any region-specific requirements, or exemptions that pertain to regional water board processes. For example, in San Diego, a dewatering permit is only necessary if the dewatering quantity exceeds 100,000 gallons per day.

Table 4.2 Examples of Pilot Study Activities Requiring Environmental Permits/Approvals

Activity	Possible Permit/Approval
Constructing any part of a BMP pilot within Coastal Zone (except in the San Francisco area)	CCC Coastal Development Permit
Constructing any part of a BMP pilot in San Francisco within 3,000 feet of the coast	BCDC Coastal Development Permit
Constructing any part of a BMP pilot in the Lake Tahoe Watershed	TRPA Project Permit
Constructing any part of a BMP pilot in a Lake Tahoe Stream Environment Zone	TRPA Project Permit
Constructing any part of a BMP pilot within the floodway of a Central Valley stream regulated by the Reclamation Board	Reclamation Board Encroachment Permit
Constructing any part of a BMP pilot on a federal flood control levee or within the surrounding 10-foot Reclamation Board easement	Reclamation Board Encroachment Permit
Constructing an outlet pipe that directly connects to a waterbody or channel regulated as a Water of the U.S.	ACOE Section 404 Permit and RWQCB Section 401 Water Quality Certification
Discharging groundwater to a receiving water during geotechnical investigations	RWQCB NPDES Permit
Discharging groundwater to a receiving water during dewatering operations	RWQCB NPDES Permit
Removing (either temporarily or permanently) existing wildlife habitat within a USGS Blue Line Stream	CDFG Section 1602 Streambed Alteration Agreement, ACOE Section 404
Removing (either temporarily or permanently) existing protected habitat (such as Coastal Sage Scrub)	CDFG Section 1602 Streambed Alteration Agreement
Removing (either temporarily or permanently) existing habitat used by federally endangered species (such as the California Gnatcatcher)	USFWS Biological Opinion
Excavating in an area known to have archaeological significance and/or Native American concerns	SHPO NHPA Section 106 Programmatic Agreement; Native American Tribes Consultation
* this list is not all-inclusive.	

4.1.2.1 Project Location

Work within certain geographic areas within the state may require a specific permit or approval, regardless of the pilot facility itself and any protected resources that may be affected. The two most common areas that require agency coordination are the Coastal Zone and the Lake Tahoe basin.

Coastal Zone. "Coastal Zone" refers to the land and water area of the State of California from the Oregon border to the border of the Republic of Mexico, extending seaward to the state's outer limit of jurisdiction (3 miles, offshore), including all offshore islands, and extending inland generally 3,000 feet from the mean high tide line of the sea. In significant coastal estuarine, habitat, and recreational areas it extends inland to the first major ridgeline paralleling the sea or five miles from the mean high tide line of the sea, whichever is less, and in developed urban areas the zone generally extends inland less than 3,000 feet. The CCC maintains detailed maps of the Coastal Zone for each coastal county, and should therefore be consulted to determine if a specific site is actually within the Coastal Zone.

The CCC, in partnership with coastal cities and counties, plans and regulates the use of land and water in the Coastal Zone. In the San Francisco Bay and surrounding tributaries, development in the Coastal Zone is regulated by the Bay Conservation and Development Commission (BCDC)[4].

If the pilot facility is located within the Coastal Zone, a coastal development permit will likely be required from the CCC, the BCDC, or the local government. Additional information on the Coastal Zone and associated permits may be found in the SER Volume 1, Chapter 18, at www.dot.ca.gov/ser/vol1/sec3/special/ch18coastal/chap18.htm.

Examples from the Files ....

During the design of the I-5 / Palomar Road Biofiltration Swale Pilot BMP, it was discovered that the site was within the Coastal Zone, and the adjacent trees had to be protected in accordance with the Coastal Development Permit (CDP) in effect for the Cannon Road improvements. The CDP required that any existing trees removed by construction activities had to be replaced at a 5:1 ratio. To avoid tree disturbance and mitigation, the BMP was redesigned using short concrete channels to convey the runoff around the trees. As a result, the BMP final design consisted of three biofiltration swales and two intermediate concrete swales. Additional protection was provided by restricting excavation activities to the area beyond the tree dripline.

Lake Tahoe. Lake Tahoe is a unique national treasure known for its beauty, clarity, and many recreational opportunities. It is designated as an *Outstanding Natural Resource Water*, a special designation under the Clean Water Act. Since measurements began in the 1960s, Lake Tahoe has been losing an average of one foot of clarity per year and is currently listed as an Impaired Water Body by the California State Water Resources Board under the Clean Water Act Section 303(d). In October, 1998, Lake Tahoe was listed as a Category I impaired priority watershed under the California Watershed Assessment.

[4] The jurisdiction of the BCDC is defined as follows:
The open water, marshes and mudflats of greater San Francisco Bay, including Suisun, San Pablo, Honker, Richardson, San Rafael, San Leandro, and Grizzly Bays and the Carquinez Strait.
The first 100 feet inland from the shoreline around San Francisco Bay.
The portion of the Suisun Marsh – including levees, waterways, marshes, and grasslands – below the ten-foot contour line.
Portions of most creeks, rivers, sloughs, and other tributaries that flow into San Francisco Bay.
Salt ponds, duck hunting preserves, game refuges, and other managed wetlands that have been diked off from San Francisco Bay.

The TRPA is charged with protecting the water quality of Lake Tahoe and issues permits for activities within the Lake Tahoe Basin. If the pilot study is located within the Lake Tahoe Basin, a TRPA permit will most likely be necessary. Additional information on TRPA may be found at www.trpa.org/.

> ***Examples from the Files ....***
>
> The Detention Basin with Outlet Skimmer pilot BMP at the Route 73 and Route 133 Separation was created by retrofitting an existing Compost Stormwater Filter BMP. However, to achieve the necessary basin capacity, the existing basin invert had to be lowered. As a result, the outlet channel discharge point had to be moved 200 feet further downstream. Upon review by the Environmental Planning Unit, it was discovered that the outlet channel was a Water of the United States. Therefore, a RWQCB Section 401 Water Quality Certification and ACOE Section 404 Permit were necessary to construct the new discharge point.

Stream Environment Zones (SEZs) and related hydrologic zones consist of the natural marsh and meadowlands, watercourses and drainage ways, and floodplains that provide surface water conveyance from upland areas into Lake Tahoe and its tributaries. SEZs are determined by the presence of riparian vegetation, alluvial soil, minimum buffer strips, water influence areas, and floodplains. The TRPA is responsible for the long-term preservation and restoration of SEZs.

TRPA policy requires the preservation of existing naturally functioning SEZ lands in their natural hydrologic condition; restoration of all disturbed SEZ lands in undeveloped, un-subdivided areas; and restoration of SEZ lands that have been identified as disturbed, developed, or subdivided to obtain a 5 percent total increase in the area of naturally functioning SEZ lands. Therefore, if the pilot facility must be located within or adjacent to a SEZ, coordination with the TRPA is required and mitigation may be necessary. In addition to water quality, TRPA has eight other thresholds to be met as part of the permitting process. Scenic resources could be affected by the proposed pilot projects. Additional information on SEZs may be found on the TRPA website at www.trpa.org/, and on the California Tahoe Conservancy website at www.tahoecons.ca.gov/library/progrep/sez.html.

4.1.2.2 Affected Resources

Federal, state, and local regulations are in place to ensure that protected resources are not impacted by projects without appropriate coordination and approval. The primary categories of resources that the pilot projects may impact are wetlands and waters of the U.S., cultural resources, and biological resources.

<u>Wetlands and Waters of the U.S.</u> The purpose of the Clean Water Act of 1977 and 1987 is to restore and maintain the chemical, physical, and biological integrity of the nation's waters

through prevention and elimination of pollution. Section 404 of the Clean Water Act establishes a permit program administered by the USACE regulating activities affecting waters of the United States. Waters of the United States include surface waters such as navigable waters and their tributaries, all interstate waters and their tributaries, natural lakes, all wetlands adjacent to other waters, and all impoundments of these waters.

Section 401 of the Clean Water Act requires a water quality certification from the SWRCB or Regional Water Quality Control Board when a project: 1) requires a federal license or permit (such as a USACE Section 404 permit); and 2) results in a discharge to waters of the United States.

Sections 1600 through 1616 of the California Fish and Game Code were adopted to protect waters under state jurisdiction. Section 1602 of the code requires the DFG to be notified prior to any project which would divert, obstruct, or change the natural flow or bed, channel, or bank of any river, stream, or lake.

Under the federal regulations, if the pilot study impacts a water of the U.S., a Section 404 Permit and a Section 401 Water Quality Certification may be necessary. For example, installing a new discharge point from a BMP into a water of the U.S. requires a permit. However, some of the nationwide permits do not require notifying the USACE to conduct specific activities. The permit itself will say if and when notification is required. Nonetheless, most applicants inform the USACE when a 401 Water Quality Certification is required. Under the state regulations, if the pilot study impacts a state-jurisdictional water, a Section 1602 Streambed Alteration Agreement may be necessary.

Cultural Resources. Cultural resources encompass archaeological, traditional, and built environment resources, including but not necessarily limited to buildings, structures, objects, districts, and sites. Qualified cultural resources professionals, consulting with their peers, Native Americans, subject matter experts, or review authorities as necessary, conduct studies of those cultural resources that could have potential to possess significance and that could be affected by transportation projects.

If it is determined by the PDT, in coordination with the District Environmental Branch, that the pilot study could affect a cultural resource, coordination and/or consultation with the appropriate agency (e.g., the State Historic Preservation Office or the Bureau of Indian Affairs) may be required. Additional information on cultural resources and associated approvals may be found in the SER Volume 1, Chapter 28, at www.dot.ca.gov/ser/vol1/vol1.htm, and in the SER Volume 2, at www.dot.ca.gov/ser/vol2/vol2.htm.

Biological Resources. Caltrans must comply with federal and state environmental laws and regulations designed to protect biological resources in all phases of project planning and development, construction, permitting, and maintenance. Biological resources include Habitats and Vegetative Communities, Migratory Corridors, Plants, Wildlife, Fisheries, and Special Status Species (regulated by a law, regulation, or policy, such as threatened and endangered species). Federal agencies associated with the protection of biological resources include the U.S. Fish and Wildlife Service, USACE, and the CDFG. The PDT in coordination with the District Environmental Branch will determine if any biological resources are affected by the pilot study and what coordination is required with the appropriate resource agencies. Additional information on biological resources may be found in the SER Volume 1, Chapter 14, at www.dot.ca.gov/ser/vol1/vol1.htm, and in the SER Volume 3, at www.dot.ca.gov/ser/vol3/vol3.htm.

4.1.3 Construction Activities

Federal, state, and local agency coordination may also be required depending on what activities will be performed during construction of the pilot facility. The PDT will determine the complete list of necessary permits and approvals during project development. In addition to any permit conditions already identified for the project, other activities during construction that may result in agency coordination are managing hazardous wastes and encroaching upon local streets and highways.

4.1.3.1 Hazardous Wastes

Hazardous wastes are different from other environmental issues in that sites contaminated with hazardous wastes will have an impact on the project rather than the project having an impact on the environment. Hazardous waste and hazardous materials include chemicals discharged to the environment that may adversely impact the environment or human health and safety. As presented in the SER, the word "contamination" is also used to indicate soil and ground water impacted by chemicals.

> **Examples from the Files ....**
>
> The design of the Route 73 Full Sedimentation Earthen Berm Austin Sand Filter Pilot BMP required excavation depths of up to five feet. During construction, unsuitable hazardous material from an apparent old abandoned dump site was discovered at lower depths. This hazardous material was not identified during the design-phase field investigations. The contractor was directed to over-excavate the area to remove all the material and replace it with Imported Borrow. The cost of this work (close to $200,000) utilized all the contract contingency funds and forced a suspension of the contract until additional funds were secured.

The most common hazardous waste that might be encountered during the construction of a pilot study is aerially deposited lead (ADL) in the soil. In the past, Caltrans has applied for and received variances from the California Department of Toxic Substances Control (DTSC) for the reuse of some lead-contaminated soils in certain Districts. The current variance allows Districts 4, 6, 7, 8, 10, and 11 to reuse lead-contaminated soil within Caltrans right-of-way in the roadway corridor boundaries under certain conditions if the soil was considered a non-Resource Conservation and Recovery Act (RCRA) waste. Districts not subject to the variance are required to haul all contaminated soil off to an appropriate disposal facility. The Caltrans permit requires written notification to the RWQCB at least 30 days prior to advertisement for bids of projects that involve soils subject to the variance. The RWQCB will then determine the need for development of Waste Discharge Requirements (WDRs) or written conditional approvals by RWQCB staff. It is recommended that the notification be submitted as early in the design phase as possible because the RWQCB may take as long as 180 days to issue WDRs. In addition, if the variance is to be invoked, public notification is required and the DTSC must be notified at least five (5) days prior to construction. Coordination with the District NPDES Coordinator is required to determine if a variance is in effect at the time of the pilot study and the appropriate procedures are in place.

If lead is determined to be present in the soil at concentrations considered hazardous, the contract documents will have to clearly identify the contaminated soil and provide appropriate re-use/disposal procedures. Additional information on hazardous wastes may be found in the SER Volume 1, Chapter 10, at www.dot.ca.gov/ser/vol1/vol1.htm. Additional information on the lead variances may be found on the Division of Environmental Analysis Hazardous Waste Management website at www.dot.ca.gov/hq/env/haz/index.htm.

4.1.3.2 Encroachments

Although the pilot facility may be located within Caltrans right-of-way, access from a non-Caltrans roadway might be necessary. For example, if the pilot facility is constructed adjacent to an elevated roadway, the best access might be from a city street and not from the roadway itself. If this is the case, a driveway approach might be needed to get from the city street to the pilot facility. This approach is an encroachment upon the city’s right-of-way and requires a permit from the city.

4.1.4 Environmental Commitments Record

An Environmental Commitment is a measure that Caltrans or a local agency commits to implement in order to avoid, minimize, and/or mitigate a real or potential environmental impact. It can be identified as early as the planning and scoping stages, during the ED or design processes, or as late as construction or maintenance of a project. It can be something as simple as a requirement for seasonal work windows or as complex as a treatment plan for cultural resources.

An Environmental Commitment Record (ECR) is now required for all Caltrans projects. The form of the ECR is determined at the District level. Current examples of ECRs include the Mitigation Monitoring and Reporting Record (MMRR); the Permits, Agreements and Mitigation (PAM) Record; and Red Book. For details, see the June 10, 2005 memorandum by the Caltrans Chief Engineer. In addition, the ECR form is available on the SER.

An ECR tracks and documents the completion of Environmental Commitments through the Project Delivery Process. It brings all the relevant environmental compliance information together in a single place, making it easier to track progress and easier for project team members (Environmental staff, Project Engineer, Project Manager, Resident Engineer) to identify actions they need to take. The ECR also aids in preparing and updating the Resident Engineer Pending File, executing Environmental Certification at the Ready to List stage, and preparing the Certificate of Environmental Compliance (CEC).

For a listing of typical commitments, see the guidance document attached to the memorandum and titled "ECR Standards and Instructions." This document guides you to ask the "who, what, when, and where" questions to help logically document the commitments. An ECR will be prepared by the A-E Consultant for each pilot study project, and will be reviewed by the District Environmental staff and PDT.

4.1.5 Traffic Control Certification

A Traffic Control Contractor must be certified to perform lane or shoulder closures. Specifically, the Traffic Control Contractor must possess a valid, current C31 license. A Traffic Control Contractor prepares or removes lane closures, flagging, or traffic diversions, utilizing portable devices, such as cones, delineators, barricades, sign stands, flashing beacons, flashing arrow trailers, and changeable message signs, on roadways, including, but not limited to, public streets, highways, or any public conveyance. This requirement applies to all phases of a project where lane closures are required. For additional information, see the Business and Professions Code, sections 7008, 7058, and 7059.

Lane closures must be registered with the respective Caltrans District Traffic Management Control (TMC) before the Traffic Control Contractor can perform the closure. The closure needs to be scheduled two weeks in advance. Once a closure is registered with the respective District TMC, an authorization number and approved work hours will be issued. The Traffic Control Contractor must call the respective District TMC with a valid authorization number each time a closure is set up and removed. If an EP was issued for the pilot study, the respective District Encroachment Permit office will register the closure with the District TMC and issue the authorization number and approved work hours. If the pilot study is being performed under an A-E Contract, and no encroachment permit was issued, the HQ PDT will register the closure with the respective District TMC and issue the authorization number and approved work hours.

All lanes closures must conform with the appropriate Traffic Control System included on Plan Numbers T10 – T17 of the July 2002 Caltrans Standard Plans.

4.2 Environmental Clearance, WBS 165 - 180.10

Environmental clearance involves preparation of the ED by the PDT unless otherwise instructed by the Caltrans Contract Manager or as directed by the local District Environmental Branch. Specific environmental clearance requirements may vary by District, so it is important to coordinate efforts with appropriate District Environmental Branch staff as early in the permitting/approval process as possible.

Depending on the funding source of the pilot study, it will fall under the jurisdiction of CEQA and may also fall under NEPA. As all projects require environmental review, HQ Stormwater will contact the designated District Environmental Staff for direction on any technical studies needed to be performed by professional archaeologists and/or biologists to complete the environmental documentation (such as for water quality, biological, or cultural resources). For each site, procedures in the Standard Environmental Reference (SER) for CEQA (and NEPA if needed) compliance shall be followed. However, given that specific requirements may vary from one District to another, appropriate procedures should be confirmed with the District Environmental Branch prior to initiating any technical studies. Specific guidelines for CEQA and NEPA compliance are provided in the SER, Volume 1, Guidance for Compliance (www.dot.ca.gov/ser/vol1/vol1.htm).

Effective July 1, 2007, the Department has been assigned environmental review and consultation responsibilities under NEPA pursuant to Section 6005 of the Safe, Accountable, Flexible, and Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) (23 U.S.C. 327). The assignment applies to all projects on the State Highway System (SHS) and all Local Assistance projects off the SHS, with the exception of responsibilities assigned for certain CEs under the June 7, 2007 Memorandum of Understanding (MOU) with the Federal Highway Administration (FHWA), projects excluded by definition, and specific project exclusions. On projects for which Caltrans has assumed NEPA responsibilities, Caltrans has also assumed responsibility for environmental review and consultation under other federal environmental laws. Refer to Chapter

38 of the SER (http://www.dot.ca.gov/ser/vol1/sec6/ch38nepa/chap38.htm) for detailed guidance on the policy and procedures for compliance with NEPA and other federal environmental laws, regulations, and executive orders for projects assigned to the Department.

Compliance with NEPA is required if the pilot project will also involve federal funding or approval by the FHWA, or Caltrans as assigned by the FHWA (23 U.S.C. 327), or a permit or approval from a federal agency. Under NEPA, the ED may be a CE, EA, or EIS. The preferred document under NEPA is the CE because it indicates minimal or no environmental impacts, which requires the following conditions:

- The project does not have a significant impact on the environment.
- The project does not involve substantial controversy on environmental grounds.
- The project does not involve significant impacts on publicly owned lands of a public park, recreation area, or wildlife and waterfowl refuge of national, state, or local significance, or land of an historic site of national, state, or local significance.
- The project does not involve significant impacts on properties protected by the National Historic Preservation Act.
- The project comes from either a currently conforming plan and Transportation Improvement Program, or is exempt from regional conformity.
- The project is consistent with all federal, state, and local laws relating to the environmental aspects of the project.

CEQA compliance is required for pilot projects for which Caltrans has a discretionary action unless the project is exempted by statute in an act of the state legislature. Under CEQA, the ED may be a CE, IS, or EIR. The preferred document for a pilot study is the CE, which means that there is no possibility that the pilot study may have a significant effect on the environment. To qualify for a CE, the following criteria must be met:

- The project does not impact an environmental resource of hazardous or critical concern.
- There will not be a significant cumulative impact by the project and successive projects of the same type in the same place, over time.
- There is not a reasonable possibility that the project will have a significant effect on the environment due to unusual circumstances.
- The project does not damage a scenic resource.
- The project is not located on a site that is listed on the DTSC Hazardous Waste and Substances Site List (Cortese List).

- The project does not cause a substantial adverse change in the significance of an historical resource.

Additional information on preparation of EDs may be found in the SER, at www.dot.ca.gov/ser/ and Section 4.2.

4.3 Task Order Development

Unless directed otherwise by the Department Task Managers, task orders with environmental clearance and permit/approval activities should include, at a minimum, the following scope elements (with language as proposed):

4.3.1 Draft Environmental Document

The Department Task Manager shall provide project information and mapping to the designated PDT contact when a pilot study project is proposed. Based on direction from District staff, the necessary environmental documentation shall be completed. Any environmental technical studies (such as for water quality, biological, or cultural resources) required by District Environmental staff will be performed following the approval of the Department Task Manager. Coordination and consultation with District staff shall be performed as needed. The draft and final technical reports shall be reviewed and approved by District Environmental staff. The procedures in the SER shall be followed, including the preparation of environmental approval documents for CEQA and possibly NEPA compliance. Draft environmental documents shall be submitted to the Department Task Manager for distribution and review by the PDT and

> ***Examples from the Files ....***
>
> The installation of stormwater monitoring stations in Northern California Region required the filing of a Categorical Exemption that included technical studies examining biological resources and cultural resources at the installation sites.
>
> The biological documentation included a letter report documenting development of a species list for each monitoring station's 7.5-minute quadrangle by searching the California Natural Diversity Database (CNDDB) and the Sacramento U.S. Fish and Wildlife Service (USFWS) website; and examination of photos of the site to determine the existing conditions at each location and the possibility for special-status species to occupy these sites. Where necessary a 9-quadrangle species list was obtained from the CNDDB and the California Native Plant Society Inventory.
>
> The archeological documentation included historical resource compliance reports prepared by professional archeologists. The archeological survey were performed in accordance with the Caltrans Section 106 Programmatic Agreement (Section 106 PA) and CEQA Guidelines §15064.5(a).
>
> Aerially deposited lead was the only hazardous waste concern at the monitoring stations. An email from the North Region Environmental Engineering Office stating that previous testing in the region of the monitoring stations showed aerially deposited lead levels below hazardous concentrations.

District Environmental staff. If necessary, environmental documents shall be circulated for public review.

- Deliverables:
  - Draft Environmental Document

4.3.2 Final Environmental Document

Following Department review and receipt of Department comments on the Draft Environmental Document, revised documents shall be prepared and submitted to the Department Task Manager. The Department must sign the form and make the final determination.

- Deliverables:
  - Final Environmental Document

4.3.3 Permits and Approvals

All EPs and environmental permits/approvals necessary to conduct the pilot study shall be identified. Coordination with the appropriate District EP Office and resource agencies shall be conducted and the necessary permit applications and supporting information shall be prepared by the PDT. Application submittal and payment of permit fees shall be performed by the Department DEA Stormwater Program.

- Deliverables:
  - Permit Applications and Supporting Information

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Chapter 5 Project Design

The Project Design phase, also known as the Plans, Specifications, and Estimate (PS&E) phase consists of preparing the contract documents for any pilot study construction activities. This chapter presents guidelines for performing design-related activities for a pilot study in which construction activities will be performed by the A-E Contract Delivery Method. Refer to Appendix A for guidelines when another delivery method is being used. Figure 5-1 presents the overall process flowchart for the design phase. Section references are provided in the flowchart to facilitate cross-referencing to the text. Tasks in which District NPDES Coordinator involvement is recommended are identified with an "*".

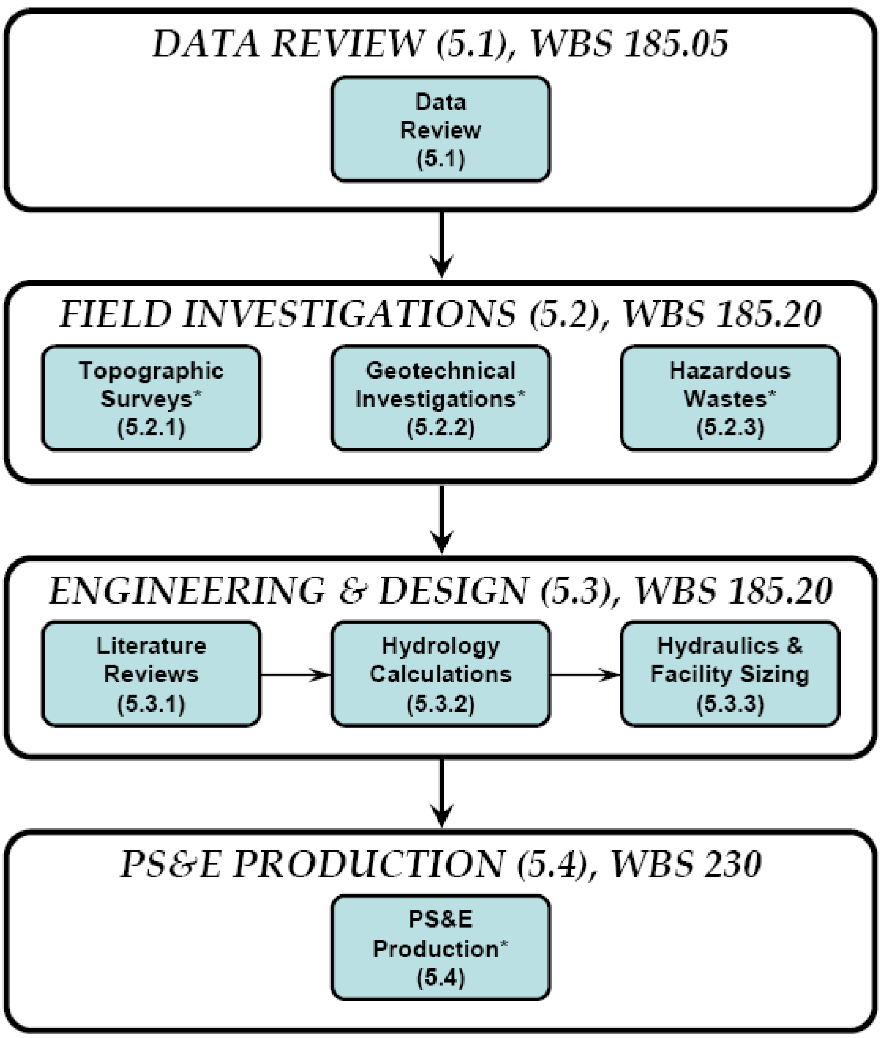

Figure 5-1 Design Phase Process Flowchart

During the Project Design phase, the contract documents (plans, specifications, and estimate) are prepared for the construction of the pilot. Tasks performed during this phase include data collection/review, field investigations (topographic surveys, geotechnical investigations, and hazardous materials investigations), engineering and design (hydrology, hydraulics, facility sizing, and layout), and production of the PS&E.

The execution of the various design tasks are governed by one or more of the following Caltrans documents:

- Ready-to-List (RTL) and Construction Contract Award Guide, which provides guidance on preparation of special provisions and cost estimates.
- Implementation and Distribution of the July 2004 Standard Plans Memorandum, which provides guidance on when the 2004 standard plans must be used.
- Cross-Section Preparation and Delivery Memorandum, which provides guidance on the preparation of cross sections for the Resident Engineer file.
- Project Development Procedures Manual, which presents the overall design process.
- Plans Preparation Manual, which provides guidance on the format and content of the contract plans.
- CADD Users Manual, which provides guidance on the format and content of the electronic design files.
- Stormwater Quality Handbooks, Project Planning and Design Guide, which provides guidance on sizing and selecting BMPs.
- Highway Design Manual, which provides guidance on sizing of roadway drainage structures.

Depending on the specific needs of the pilot study (e.g., schedule constraints), the Department Task Manager may waive the necessity to comply with one or more of the above documents.

5.1 Data Review, WBS 185.05

The first step is to review the Study Plan TM, including key siting and design parameters, and information collected during site selection (in the Site Selection TM) for completeness and accuracy. Additional/supplemental information requirements should be brought to the attention of the Caltrans Task Order Manager in a TM as soon as possible such that it may be collected during subsequent field investigations before engineering and design activities commence.

5.2 Field Investigations, WBS 185.20

Field investigations are performed to collect information that was not collected during site selection and/or to determine current site characteristics and conditions. They are conducted prior to PS&E preparation, and can take anywhere from 4 to 12 weeks to complete, depending on the number and size of pilot sites.

5.2.1 Topographic Surveys

The need for a survey should be evaluated by the PDT. In general, surveys are performed for most pilot projects. Surveys are performed to accomplish two primary objectives:

- Provide an accurate base map for the layout and design of the BMP.
- Verify information utilized during site selection, such as preliminary tributary drainage areas, WQV and/or WQF, and existing drainage facility connectivity (i.e., the layout of the drainage system as shown in as-builts).

The first objective is achieved by a topographic survey, which can be accomplished by either aerial photography (with ground control) or a ground survey. In either case, the result is usually a digital terrain model of the area with existing grade contours, existing visual roadway and drainage features (e.g., roadways, shoulders, curbs and dikes, barriers, light standards, drain inlets, manhole covers, etc.), and spot elevations of existing visual features (e.g., outfall pipe invert elevations, manhole/drain inlet rim elevations, etc.). The survey should include the immediate project site and enough of the surrounding area to support the design of Construction Area Sign and Traffic Handling elements.

The second objective may also be achieved with a topographic survey, but given that tributary drainage areas can cover large areas, this approach may not be cost effective for a particular project. This is especially true if a ground survey is performed, as it may require lane and ramp closures, which may only be permitted during evening and weekend hours and with close coordination with the District and the Department Task Manager. Therefore, a visual reconnaissance survey may be a more cost effective alternative to adequately delineate larger drainage areas. Under this approach, drainage areas are delineated on as-built plans and then field verified (to confirm high and low points, grade breaks, flow paths, etc.).

> ***Examples from the Files ....***
>
> For the BMP Retrofit Pilot Study, drainage areas were determined from topographic surveys. For the State Route 73 Pilot Studies, drainage areas were determined using as-built drawings and visual reconnaissance surveys. Acceptable results were achieved in both studies.

The final objective, verifying drainage facility connectivity, may also be carried out by either a ground survey or an as-built verification reconnaissance survey. However, for the same reasons as those presented above, this verification is usually performed by checking as-built information.

Cost Reduction Strategies $

✓ Perform adequate site and geotechnical surveys to avoid unexpected costs and ensure post-construction BMP effectiveness, especially for infiltration type BMPs.

5.2.2 Geotechnical Investigations

The need for a geotechnical investigation should be evaluated by the PDT. In general, geotechnical investigations should be considered for most pilots. Geotechnical investigations are an essential design support activity that are conducted to determine current soil and groundwater conditions at the project site and to identify geotechnical constraints that must be incorporated into the design. This work is performed by licensed professionals, who provide the project Design Engineer with recommendations for embankments, fill and cut slope design, expansive and soft soil treatment, foundation bearing pressures, groundwater control, seismic stability, potential liquefaction, retaining walls, earth/water retaining structures, sound walls, and culvert foundations. Coordination with the District NPDES Coordinator is recommended to identify any District-specific reporting requirements (e.g., if a licensed civil engineer may sign the report or if the signature of a licensed geotechnical engineer or geologist is required). The work typically includes the following activities:

- Literature search
- Review of geologic maps
- Surface geologic investigation
- Subsurface geologic and geotechnical investigation
- Laboratory analysis
- Submittal of a Geotechnical Design Report that includes a log of test borings

The above list is general in nature and does not reflect specific needs of a particular pilot project. Therefore, the actual scope of work for geotechnical investigations should be determined on a project-by-project basis.

5.2.3 Hazardous Wastes

Any hazardous wastes within the project limits must be specified in the contract documents to ensure appropriate handling and disposal. Although a detailed investigation for any hazardous materials may be requested by the Department Task Manager, the most common material encountered during pilot studies, and therefore tested for, is Aerially Deposited Lead (ADL).

> ***Examples from the Files ....***
>
> The ISA for the State Route 73 Pilot Study concluded that hazardous wastes may be present at any of the 38 project sites. This was confirmed at the University Drive Phase II Inclined Screen GSRD BMP pilot site when ADL was discovered during the subsequent hazardous waste investigation. Although the excavation area covered more than 2 acres, enough samples were taken to determine that the ADL was limited to the northeast corner of the basin, thereby minimizing disposal costs.

Having accurate concentrations of ADL are important because the reuse/disposal requirements for soil containing ADL are concentration-dependent and can be rather expensive (up to 10 times more per cubic yard for soil containing ADL). The results of the site investigation are documented in the ADL Test Report (sometimes called the Site Investigation Report). Guidelines and standards for ADL testing and the appropriate analytical methods are available on the Caltrans Division of Environmental Analysis Hazardous Waste Management webpage, at http://www.dot.ca.gov/hq/env/haz/index.htm.

Given the significant difference in disposal costs, it is prudent to make an accurate assessment of exactly where the contaminated soil is present within the project site and at what concentration levels. Many times, the hazardous waste is localized in small areas, only in the top layer of soil, or only adjacent to older roadways that existed when lead-based gasoline was still in use. For that reason, the site investigation should include, when possible, enough samples to accurately delineate the limits and depths of the contaminated soil. Otherwise, a single sample might incorrectly result in all excavated material to be considered hazardous when only a small portion is actually contaminated. The most efficient strategy is to draw a grid over the excavated area and take one sample from each grid cell. The grid dimensions are flexible and should be specified on a project-by-project basis. Prior to conducting any sampling, the District Hazardous Waste Coordinator should be consulted as the District may have data or information regarding ADL concentrations within the area in question.

5.3 Engineering and Detailed Design, WBS 185.20

During engineering and detailed design, the information collected in previous activities is utilized to properly size and lay out the pilot BMP(s).

5.3.1 Literature Review

For BMPs for which there are no approved Caltrans design guidelines (e.g., BMPs that are not included in the Stormwater Quality Handbooks, Project Planning and Design Guide), a review of current literature and vendor information should be conducted to identify appropriate or "industry standard" design methods. For example, the Route 73 Pilot Study Bioretention BMP was based in part on Prince George's County Maryland design guidelines, while the District 7 BMP Retrofit Pilot Program CDS devices were based in part on vendor recommendations.

5.3.2 Hydrology Calculations

During site selection, preliminary hydrology calculations were most likely performed to help identify sites with appropriate discharge rates (e.g., WQF) or design volumes (e.g., WQV). Although these calculations were sufficient for siting purposes, they typically are not detailed or accurate enough for engineering and design purposes. For this reason, at the onset of design, the hydrology assumptions previously used need to be verified and detailed calculations must be performed. If no such evaluation was performed during siting, it must be completed now to verify that the site meets the pilot study objectives.

Hydrologic calculations utilize drainage areas, runoff coefficients, rainfall intensities, and rainfall depths to compute discharge rates (e.g., hydrographs) and runoff volumes. The discharge rates are computed for those rainfall recurrence intervals (e.g., 2-year, 10-year, 25-year, 100-year), which are necessary to meet monitoring requirements, treatment requirements, and flood control requirements. For example, peak flow rates associated with frequent small storms are necessary to size flow measuring devices, while peak flow rates associated with larger less frequent storms are necessary to set flood control design criteria.

These calculated parameters are used to size BMP treatment components, monitoring components (such as flumes and other flow measurement devices), conveyance systems (e.g., piping and open channel culverts), and flood control facilities (if flood control is required apart from water quality treatment). Additional information on highway hydrology may be found in the FHWA Hydraulic Design Series No. 2, Hydrology (www.fhwa.dot.gov/engineering/hydraulics/library_listing.cfm).

General guidelines for calculating roadway flows are provided in Chapter 810 of the Highway Design Manual (www.dot.ca.gov/hq/oppd/hdm/hdmtoc.htm). Specific guidelines for calculating BMP water quality discharge rates (WQF) and water quality runoff volumes (WQV) are provided in Chapter 2 of the PPDG (www.dot.ca.gov/hq/oppd/stormwtr/index.htm). Guidelines for performing hydrologic calculations for flood control purposes are maintained by the county in which the pilot project is located. For example, Orange County is governed by the Orange County Hydrology Manual, San Diego County is governed by the County of San Diego Department of Public Works Hydrology Manual, etc.

The program Basin Sizer, developed by the California State University, Sacramento, Office of Water Programs (www.owp.csus.edu/research/stormwatertools/), may be used to compute rainfall depths and rainfall intensities for water quality events. Another computer program is the Caltrans Rainfall Intensity-Duration-Frequency (IDF) PC Program, which incorporates the California Department of Water Resources (DWR) short duration precipitation data. These programs eliminate reading values from graphs and simplify the interpolation between rain gauge stations.

Chapter 800 of the Highway Design Manual provides a list of hydrologic software that is approved for use by Caltrans. The use of software that is not included requires the approval of the Caltrans Task Order Manager and possibly the District Hydraulic Engineer.

Examples from the Files ....

Two hydrologic software packages that are not listed in the HDM and have been approved for specific pilot studies are HydroSoft by Advanced Engineering Software (AES) and HydroCAD by HydroCAD Software Solutions, which have been used in pilot studies in Southern California and Lake Tahoe, respectively.

Following completion of the hydrology calculations, the Design Report (also known as the Drainage Report) is initiated (see Section 5.5). Subsequent design activities (hydraulics, facility sizing, and detailed design) should not commence until comments on the Draft Design Report are received and resolved.

5.3.3 Hydraulics and Facility Sizing

Hydraulic calculations utilize hydrologic data (previously computed) and existing facility data for the sizing of proposed facilities that meet pilot study program objectives as well as applicable hydraulic design criteria and standards. Hydraulic calculations are performed to compute velocities, water surface elevations, backwater effects, and scour depth in order to determine appropriate facility sizes, including:

Cost Reduction Strategies $

- ✓ Use natural landscape features and materials instead of concrete and other structural components.
- ✓ Minimize support features such as fencing, access roads, and gates to those necessary for safety and O&M.
- ✓ Minimize access road surfaces to what is necessary for O&M and use permeable materials where feasible (although permeable materials may have a higher capital and O&M cost as compared to AC).
- ✓ Utilize prefabricated components as much as possible.

- Culverts (open channels and closed conduits)
- Basins
- Treatment devices
- Outlet structures
- Flow measurement devices
- Spillways (flood control devices)
- Energy dissipaters
- Bypass flow splitters (for offline devices)

Effluent hydraulic calculations are performed to compute effluent discharge rates for the purpose of confirming that they do not exceed established design criteria. One of the results of the effluent hydraulic calculations is a series of effluent hydrographs for each recurrence period. Although many treatment BMPs are based on volume (i.e., WQV-based) and do not have a defined hydrograph, hydraulic calculations are still necessary to size other device components, such as those listed above.

Additional information on highway hydraulics may be found in the FHWA Hydraulic Design Series No. 4, Introduction to Highway Hydraulics (www.fhwa.dot.gov/engineering/hydraulics/library_listing.cfm). General Caltrans guidelines for roadway hydraulics are provided in Chapters 820 - 860 of the Highway Design Manual (www.dot.ca.gov/hq/oppd/hdm/hdmtoc.htm).

The guidelines presented previously on hydrologic software are also applicable to hydraulic software.

5.4 PS&E Production, WBS 230

The PS&E specifies what will be constructed (plans), how it will be constructed (specifications), and how much it is anticipated to cost (estimate).

Apart from the pilot facility layout and sizing information developed previously, additional details worked out during PS&E production for a pilot study may include:

- Existing facilities that must be removed, modified, or protected.
- Materials of construction for all proposed facilities.
- Foundation and wall designs for structural elements.
- Construction details for all proposed facilities.
- Temporary construction BMPs to control water pollution during construction.
- Permanent erosion control materials to control slope erosion during monitoring.
- Roads and driveways for site access.
- Construction area signs to direct the public around the project site during construction.
- Temporary traffic control measures to ensure the safety of the construction workers and the public during construction.
- Permanent barriers to ensure the safety of OM&M staff and the public during monitoring.
- Construction schedule, including identifying any constraint-driven activities.
- Accurate quantities of work items.
- Methods of payment for all work items.

Cost Reduction Strategies

✓ Utilize standard items to reduce the costs of materials needed for constructing BMPs. Continued improvement on BMP selection guidance should lead to reduced costs and BMP performance in the field.
✓ Minimize BMP design complexity. In general, non-structural (vegetation-based) BMPs are less costly than structural devices.
✓ Use natural topography and terrain to maximize BMP performance and to achieve an aesthetic balance in design and siting.

5.4.1 Plans

Project plans identify what work is to be performed and where it is to be performed. They are engineering drawings that contain information from which contractors prepare bids, surveyors stake the project, contractors build the project, and engineers inspect the contractor's work. Project plans are prepared following the guidelines in the Plans Preparation Manual and CADD Users Manual of Instruction (www.dot.ca.gov/hq/esc/oe/project_plans/). Table 5.1 presents a typical list of the drawings for a Caltrans roadway project. The sheets are listed in the order in which they appear in the plan set. The actual list used for a particular pilot study will depend on a number of factors, including purpose, complexity, required level of detail, available schedule, and available budget. For example, simple pilot studies might only include a Title Sheet, Drainage Plans, and Drainage Detail sheets, while more complex projects might use the entire list. Furthermore, certain drawings may be combined, such as the Layout, Grading, and Drainage Plan, for simple projects. For this reason, it is important to work with the Caltrans Task Manager in determining the necessary level of detail and agree on an appropriate drawing list.

Under most circumstances, pilot Study Plans will go through three rounds of submittals – draft, revised, and final. However, again depending on a number of factors, the revised and final submittals may be combined by the Caltrans Task Manager. Each submittal should include a sheet for every anticipated drawing in the plan set, and each sheet should be as complete as possible.

Table 5.1 Typical Roadway Plan Set

Sheet Name	Description/Contents
Title Sheet	Project vicinity map and limits of construction
Layouts	Layout and location of roadway items of work (access roads, driveways, fencing), existing utilities, permanent barriers (guard rail, curbs/dikes), right-of-way limits
Construction Details	Supplementary details (dimensions, materials, typical sections) of layout items of work that are specific to the project and are not in the Standard Plans
Temporary Water Pollution Control Quantities	Pay quantities of temporary water pollution control items
Erosion Control Plans	Layout and location of permanent erosion control materials
Erosion Control Quantities	Pay quantities of erosion control items
Contour Grading	Existing and proposed site grading, limits of disturbed soil, top of cut, toe of fill, limits of contaminated soils
Drainage Plans	Layout and location of existing and proposed drainage facilities (culverts, BMP structures, flow measurement devices, drainage inlets, manholes)
Drainage Profiles	Profiles of each drainage system, which permit the determination of excavation and backfill quantities
Drainage Details	Construction details for drainage items of work, which are specific to the project and are not in the Standard Plans
Drainage Quantities	Pay quantities of drainage items
Traffic Handling	Layout and location of long-term traffic control systems, to show how traffic is to be routed and maintained within the limits of the project
Construction Area Signs	Location and type of temporary signs required for the direction of public traffic through or around the project site
Summary of Quantities	Pay quantities for layout, grading, construction area signs, and traffic handling items of work
Planting Plans	Layout and location of permanent non-erosion control plants (e.g., shrubs, ground cover, trees)
Irrigation Plans	Layout and location of permanent irrigation facilities necessary to support the plants shown in the Planting Plans
Electrical Plans	Layout and location of electrical items of work (usually in support of BMP-related mechanical equipment)

5.4.2 Specifications

Whereas the plans identify what work is to be performed, the specifications identify how the work is to be performed and what material is to be supplied. This includes applicable materials standards (ASME, ASTM, AWWA, IEEE, etc.), methods of construction, and methods of payment (i.e., how items of work will be paid for). This last item is important, as every item of work must have a pay clause (i.e., specifying if the item of work is paid for separately or if the cost of providing that item is included in the price of another item). The specifications for a pilot project (or any roadway project) are typically composed of two documents – the Standard Specifications and the Contract Special Provisions. However, depending on specific pilot study needs, these documents may be waived by the Department Task Manager and appropriate specifications may be included directly on the drawings.

5.4.2.1 Standard Specifications

These are general state-wide procedures prepared and maintained by Caltrans for the management and execution of projects. Standard Specifications cannot be modified. They provide a written amplification of the information contained in the plans, the specific requirements for measurement of and payment for work performed, and a mechanism to handle situations not contemplated by the contract. An electronic version of the Standard Specifications may be found at the Office Engineers website (www.dot.ca.gov/hq/esc/oe/specs_html/1999_specs.html).

5.4.2.2 Contract Special Provisions

These are project-specific procedures prepared by the Design Engineer which supplement or supersede the Standard Specifications for a particular project. They complement the contract plans, providing legal, administrative, and technical requirements. Contract Special Provisions are made up of boilerplate Standard Special Provisions (SSPs) maintained by Caltrans and used as-is (such as most Section 5 SSPs, including Lines and Grades, Cost Reduction Incentive, Labor Nondiscrimination, and Public Safety), SSPs maintained by Caltrans and edited by the Design Engineer to meet specific project needs (such as most Section 10 SSPs, including Order of Work, Earthwork, and Existing Highway Facilities), and non-SSPs prepared by the Design Engineer for specific project needs not covered by the SSPs. Non-SSPs are not uncommon for pilot projects since these types of projects include items of work not included in normal roadway projects. Non-SSPs developed for past pilot projects include the following (contact the Office of Stormwater Management – Design for additional information):

- Fiberglass Flume
- Filter Media
- Floating Skimmer
- Geomembrane Liner
- Gross Solids Removal Device
- Roosting Bat Treatment
- Bird Exclusion Netting (Swallows)
- Hold and Release Valve
- Gate Valve
- Monitoring Well
- Trench Rock
- Tube Settlers
- Environmentally Sensitive Areas

SSPs maintained by Caltrans may be found on the Office Engineers website (www.dot.ca.gov/hq/esc/oe/specs_html/1999_specs.html).

If separate specifications are required, the first submittal of the Contract Special Provisions for a pilot study should occur at the Draft PS&E stage, and is made up of, at a minimum, the Special Provision Table of Contents (i.e., a list of special provisions that are anticipated for the project) and drafts of the major (i.e., critical) special provisions (edited SSPs and non-SSPs). A draft version of the complete Special Provisions is provided with the revised submittal. The final document is submitted with the Final PS&E.

5.4.3 Estimate

The estimate presents the expected cost of construction to Caltrans for the pilot project. For each contract item of work, the estimate includes an item code, the unit of measure (e.g., each, lump sum, cubic meter, meter), the contract quantity, the unit price (e.g., cost per meter), and the amount (equal to the unit price times the quantity). The item code is a unique identifier assigned to the item of work, and should correspond to the standard BEES (Basic Engineering Estimating System) codes maintained by Caltrans. However, these codes have been developed from roadway projects and do not always include non-standard specialty items that may be included in a pilot study. Guidelines for assigning item codes to non-standard items are provided in the RTL Guide. When using new item codes, lump sum units of measure should only be used when the item can not be quantified. Standard Coded Contract Item Lists may be found on the Office Engineers website (www.dot.ca.gov/hq/esc/oe/costinfo.html).

The unit prices are developed based on experience, engineering judgment, vendor information, and historical values from previous work. To assist with the last source, Caltrans publishes an annual Contract Item Cost Data Summary, which provides average unit rates for standard contract items from awarded contracts each year. Caution should be exercised when using this database as the rates represent weighted averages and are affected by many factors, including location, time, and quantity. The quantity of the work item is especially important in the context of pilot studies, since pilot studies typically have much lower quantities than typical roadway projects, and therefore usually have higher unit prices. Contract Item Cost Data Summaries may be found on the Office Engineers website (www.dot.ca.gov/hq/esc/oe/costinfo.html).

The construction estimate is included with each PS&E submittal (draft, revised, and final). A sample format for a cost estimate is presented in Figure 5-2.

Item	Code	Description	Unit	Qty	Unit Price	Item Total
1	74019	PREPARE STORM WATER POLLUTION PREVENTION PLAN	LS	1	$7,000	$7,000
2	74020	WATER POLLUTION CONTROL	LS	1	$15,000	$15,000
3	74028	TEMPORARY FIBER ROLLS	FT	1,310	$4	$5,240
5	74032	TEMPORARY CONCRETE WASHOUT FACILITY	EA	3	$2,000	$6,000
6	74033	TEMPORARY CONSTRUCTION ENTRANCE	EA	3	$3,500	$10,500
7	74038A	TEMPORARY INLET/OUTLET PROTECTION	EA	4	$500	$2,000
8	120090	CONSTRUCTION AREA SIGNS (S)	LS	1	$4,000	$4,000
9	120100	TRAFFIC CONTROL SYSTEM	LS	1	$45,000	$45,000
11	150806	REMOVE PIPE	FT	76	$30	$2,280
12	150821	REMOVE HEADWALL	EA	2	$1,000	$2,000
15	153219	REMOVE CONCRETE FLARED END SECTION	EA	2	$750	$1,500
16	160101	CLEARING AND GRUBBING	LS	1	$6,000	$6,000
17	190101	ROADWAY EXCAVATION	CU-YD	4,660	$30	$139,800
18	190110	LEAD COMPLIANCE PLAN	LS	1	$4,500	$4,500

Figure 5-2 Sample Cost Estimate Format

5.5 Design Report

The Design Report (DR) is prepared during PS&E preparation and is initiated following the completion of the hydrology calculations. It documents the assumptions and criteria to be used in the design of the pilot(s), provides the basis for approval and acceptance of the design, and summarizes the design of the various pilot facility components. The DR shall include, at a minimum, the following:

- Project description and location maps.
- Site Plans.
- Information collected for each site.
- Existing site conditions, including topography, climate, precipitation, soils, groundwater, and stormwater conveyance and treatment facilities.
- Hydrology methodology.
- Watershed delineation.
- Rainfall analysis.
- Influent discharge rates (i.e., hydrographs).

- WQV and/or WQF.
- Specific BMP design and monitoring criteria (including siting and design/construction parameters identified in the Study Plan TM).
- Hydraulic calculations.
- Design of treatment and monitoring components.
- Design deviations that impact the Study Plan.
- Design costs.
- Final construction cost estimate.
- Key construction features that should receive special attention during construction, if the Standard or CCO Delivery Method is used.
- Design lessons learned, which would provide valuable information for future projects (refer to Section 8.4.4 for details).
- Any special OM&M features included in the design (such as access, cleaning, monitoring, etc.) that the individuals responsible for OM&M should be aware of.

It is important to include an accurate estimate of the design costs in the Design Report because these costs need to accounted for in the pilot study life cycle costs (see Section 8.9) , and the life cycle costs are typically developed by someone other that the design team. The design costs should include all design phase activities (field investigations, engineering and design, PS&E production, management and administration, as well as costs incurred to review products), and should be reported by WBS code.

A Draft DR shall be prepared and submitted to the Caltrans Task Order Manager with the Draft PS&E and shall include a discussion of those items listed above that are relevant at the draft design stage. Design Changes Memoranda (DCM) shall be prepared and submitted with each subsequent PS&E submittal. The memoranda shall present drafts of new report sections as they are prepared, and shall document any changes to the information presented in the Draft DR that may impact the pilot study. The memoranda shall be incorporated into the Draft DR following the Final PS&E submittal, creating the Revised DR. Following receipt of comments, the Final DR shall be prepared and submitted no later than one week prior to beginning construction.

Contents of the DR shall follow the outline provided in Appendix D.

5.6 Stormwater Data Report

The Stormwater Data Report (SWDR) summarizes the stormwater quality issues of the pilot project. The SWDR is a Caltrans documentation process for stormwater decisions at each project development phase, and presents a discussion of the following:

- Project description.
- Stormwater quality design issues.
- Regional Water Quality Control Board agreements.
- Proposed design pollution prevention BMPs.
- Proposed permanent treatment BMPs.
- Proposed temporary construction site BMPs.

Pilot projects may utilize the "Short Form" SWDR. However, since pilot projects will be treated as an exception process, the format and content of the SWDR must be reviewed and confirmed by the Department Task Manager. Draft and Final versions of the SWDR shall be prepared. The Draft should be submitted with the Draft PS&E and the final version should be submitted with the Final PS&E. Detailed guidelines and instructions for preparing SWDRs may be found in the Stormwater Quality Handbook – PPDG and the Division of Design, Stormwater Management website, both of which are found at www.dot.ca.gov/hq/oppd/stormwtr/index.htm.

5.7 Typical Timelines

The PS&E is developed in phases, with Caltrans review and approval cycles at each phase. Review by the Caltrans Task Order Manager of the permanent erosion control materials is especially important to ensure that the materials do not adversely impact the pilot study results. The actual number of cycles depends on the size and complexity of the package.

Typical durations for the PS&E process are presented in Table 5.2, while a graphical timeline is presented in Figure 5-3. Timelines represented in diagonal patterns are PDT-performed tasks, and timelines represented in vertical/horizontal patterns are tasks performed by Caltrans departments who are not part of the PDT (such as District Functional Units and Office Engineer). The horizontal and backward-diagonal pattern bars represent the minimum duration (Early Start/Finish), while the vertical and forward-diagonal bars represent the maximum duration (Late Start/Finish).

Table 5.2 Typical Pilot Study PS&E Timeline

Activity	WBS	Duration (weeks)
Field Investigations	185.xx	2 - 8
Preparation and submittal of Draft PS&E	230.xx	4 – 12
Review of Draft PS&E by Department Task Manager and Others	255.05	2 – 6
Preparation and submittal of Revised PS&E	255.10	2 – 12
Review of Revised PS&E by Department Task Manager and Others	255.20	2 – 6
Preparation and submittal of Final PS&E	255.20	1 – 4
Review/approval of Final PS&E by Task Manager	255.50	1 – 4
	Total	**14 - 52**

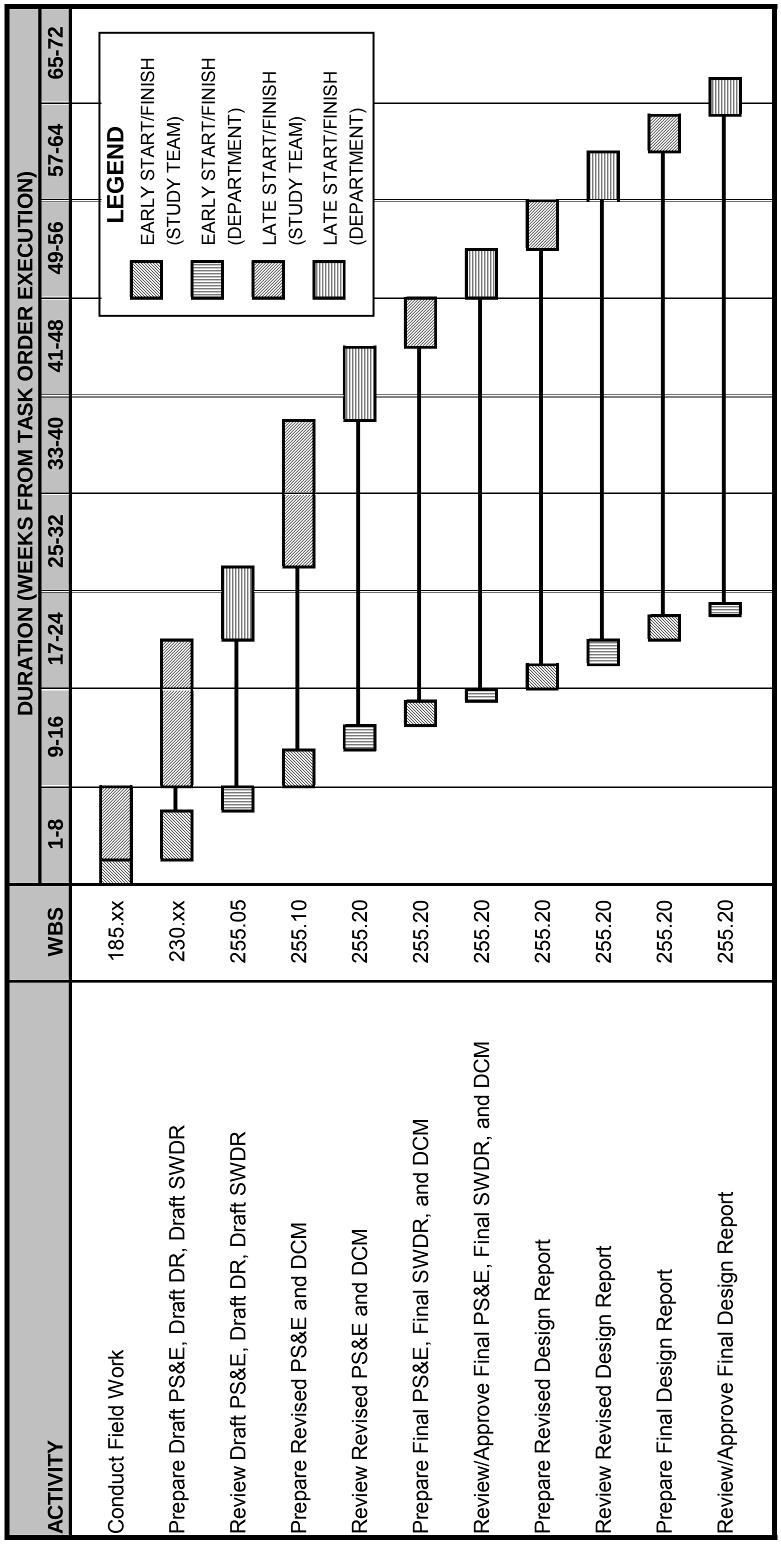

Figure 5-3 Typical Pilot Study PS&E Timeline

5.8 Task Order Development

Unless directed otherwise by the Department Task Manager, task orders with design activities should include, at a minimum, the scope elements outlined in Figure 5-4.

Scope Element	WBS	Brief Description	Deliverable(s)
ADL Site Investigation	165.10	Investigation to determine levels of ADL within project limits	ADL Report
Surveys and Mapping	185.10	Field survey to create topographic base map	Base Map
Geotechnical Investigation	185.20	Investigation to determine soil and groundwater characteristics	Geotechnical Design Report
Hydrology & Hydraulics	185.20	Hydrology and hydraulic calculations to determine size and dimensions of pilot components	Pilot Component Sizes
Draft Roadway Plans	230.05	Preparation of draft roadway drawings	Draft Plans
Draft Specifications	230.35	Preparation of draft special provisions	Draft Special Provisions
Draft Estimate	230.40	Preparation of draft quantities and construction estimate	Draft Estimate
Draft SWDR	230.60	Preparation of draft Storm Water Data Report	Draft SWDR
Draft Design Report	230.99	Preparation of draft design report	Draft Design Report
Revised PS&E	255.10	Incorporation of comments received on Draft PS&E, and preparation of Revised PS&E and DCM	Draft PS&E Review Meeting Minutes Draft PS&E Response to Comments Revised PS&E Design Change Memorandum
Final PS&E	255.20	Incorporation of comments received on Revised PS&E and Draft SWDR, and preparation of Final PS&E, Final SWDR, and DCM	Revised PS&E Response to Comments Final PS&E Final SWDR Design Change Memorandum
Final Design Report	255.20	Merging of Design Change Memorandum into Draft Design Report, and incorporation of comments received on each	Final Design Report

Figure 5-4 Design Task Order Scope Elements

Chapter 6 Project Construction

This chapter presents guidelines for performing construction-related activities for a pilot study in which construction activities will be performed by the A-E Contract Delivery Method. Refer to Appendix A for guidelines when another delivery method is being used. Figure 6-1 presents the overall process flowchart for the construction and post-construction phases. Section references are provided in the flowchart to facilitate cross-referencing to the text. Tasks in which District NPDES Coordinator involvement is recommended are identified with an "*".

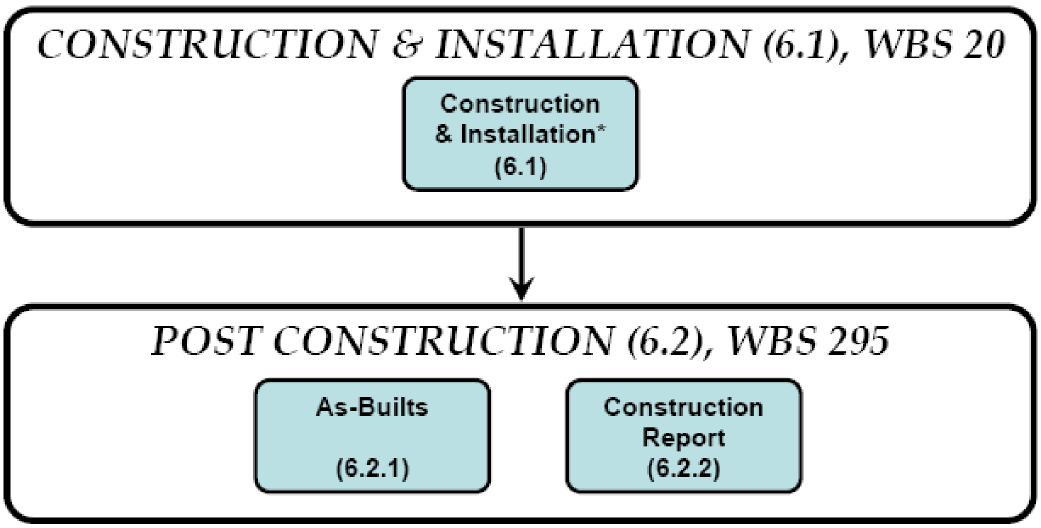

Figure 6-1 Construction Process Flowchart

6.1 Construction and Installation, WBS 270

Under the A-E Contract Delivery Method, construction and installation are performed by an A-E Consultant. When the drawings and specifications are prepared by the same Consultant who is providing the construction/installation services, the Consultant's Resident Engineer and inspection staff bear primary responsibility for the work. The local Caltrans district Construction group may assign a Resident Engineer and/or Inspector(s) who shall serve as observers. If an EP was necessary (see Section 4.1.1), the local District EP Office provides an EP Officer who acts as a part-time Inspector to verify that the work is being performed in accordance with the issued EP.

6.1.1 Water Pollution Control, WBS 270.20

In order to control the discharge of pollutants during construction, Caltrans requires the development and implementation of either a Stormwater Pollution Prevention Plan (SWPPP) or a

Water Pollution Control Program (WPCP). In accordance with Caltrans' General Construction Permit, a SWPPP is required if either the construction activities result in soil disturbances of at least 0.4 hectares (1 acre) of total land area, or if the project is considered part of a larger Common Plan of Development totaling 0.4 hectares (1 acre). A WPCP is not required by the permit, but is currently required by Caltrans for all other cases. The SWPPP, or the WPCP, shall be certified by the Consultant's Resident Engineer and reviewed for acceptability by the Caltrans Construction representative. If a SWPP is required then the Consultant must also prepare a Notice of Construction (NOC), which must be submitted to the RWQCB 30 days prior to construction.

Guidelines for preparing SWPPPs, WPCPs, and templates and samples may be found on the Division of Construction website, at www.dot.ca.gov/hq/construc/stormwater/manuals.htm.

6.1.2 Hazardous Waste Management, WBS 270.20

If ADL was discovered within the project limits during the planning, environmental clearance, or design phase, a Lead Compliance Plan is required and shall be certified by the Consultant's Licensed Occupational Hygienist. The Consultant's Resident Engineer then reviews/approves the plan in accordance with Caltrans Hazardous Waste Lead Compliance Plan Checklist. In addition, an ADL Excavation and Disposal Plan will be required and shall be certified by the Consultant's Resident Engineer.

6.1.3 Submittals, Requests for Information, and Requests for Clarification, WBS 270.20

Because the A-E Consultant who prepared the drawings and specifications may also be the Contractor, there may or may not be any formal submittals or Requests for Information (RFIs) or Requests for Clarification (RFCs) between the construction staff and the engineering/design staff. However, significant construction-initiated design changes should be brought to the attention of the Permit Officer (if an EP was required) and the Caltrans Task Manager in a timely manner. Any deviations from the contract plans must be brought to the attention of the Department Task Manager immediately.

6.1.4 Progress Documentation, WBS 270.30

In order to document and report construction progress, daily construction reports are prepared and submitted to the EP Officer (if an EP was required) and Caltrans Task Manager. The Daily Construction Report includes the following information:

- Contract Number and Task Order Number
- EP Number and Site ID/Name
- Date of the report
- Names of EP Officer and Caltrans Task Manager
- Weather conditions
- Contractor personnel and visitors on site
- Equipment on site
- Summary of daily progress
- Concerns and or issues
- Summary/status of key construction features
- Name and signature (electronic) of individual preparing report

The entries in the "Construction Issues/Concerns Discussed" section should be assigned a numerical number to facilitate tracking, and a running log should be maintained and submitted to the Department Task Manager during the construction phase. The entries in the "Key Construction Items" section must be approved by the Department Task Manager. The report should be submitted within three working days of the date of the report. An example Daily Construction Report is presented in Figure 6-2.

In addition, the A-E Consultant responsible for the construction/installation is required to maintain a set of redline plans at the construction site to document design changes made during construction for the purpose of preparing the as-built drawings (see Section 6.2.1). Information to be shown on the redlines is presented in Chapter 5 of the Caltrans Construction Manual (www.dot.ca.gov/hq/construc/manual2001/).

District 12 Route 73 Pilot Study
Daily Construction Report

Date:	10/19/05
Permit Number:	12-0C9854
BMP Site ID:	780R
Permit Officer:	Diba Kazerani
Dept. Task Mgr:	Tim Sobelman

Day	S	M	T	**W**	Th	F	S
Weather	Bright	Sunny	**Over Cast**	Rain	Snow		
Temp.°F	<32	32-50	50-70	**70-85**	85-100		
Wind	**Still**	Moderate	High				
Humidity	Dry	**Moderate**	Humid				

Manpower		
Contractor	**No.**	**Remarks**
Foremen / Superintendents	1	
Laborers	7	
Visitors	1	Permit Officer, David Alderete

Equipment on Site

- 1 – Komatsu PC228USLC Track Hoe
- 1 – Cat 936F Loader
- 1 – Cat 420D Backhoe/Loader
- 1 – Kubota KH-60 Track Hoe
- 1 – Electronic Sign Board
- 1 – Dynapac 4469 6ft Sheepsfoot Roller
- 1 – 2000 Gallon Water Truck
- 1 – Case 60XT Loader
- 2 – Wacker Trench Roller
- 1 – Wacker Vibratory Rammer

Construction Activities

- Limited production due to rain on the 17th
- Completed backfill of CSF area
- Placed and compacted base at inflow monitoring location
- Installed rebar for walls at outflow monitoring location
- Continued trenching for pipe installation

Construction Issues/Concerns Discussed

3. Met with Inspector. Concerns discussed were: 1) unexpected dewatering required for trenching to the concrete channel 2) unexpected dewatering required for excavating for the inflow monitoring station floor

Key Construction Items

Item	Installed yet?	
Outlet Riser	☐ Yes	☒ No
Monitoring	☐ Yes	☒ No
Skimmer	☐ Yes	☒ No

Figure 6-2 Example Daily Construction Report

6.2 Post-Construction, WBS 295

Once construction of the pilot project has been completed, there are only three outstanding responsibilities of the PDT:

- Preparation of as-built drawings
- Preparation of the Construction Report
- Certificate of Environmental Clearance

6.2.1 As-Builts, WBS 295.15

As-built plans (sometimes also referred to as record drawings) are prepared following completion of construction and represent existing field conditions at the completion of the project. As described above, the as-builts are based on the set of redlines maintained by the consultant/contractor during construction. Final as-builts are to be submitted to the Department Task Manager and the District. Coordination with the District NPDES Coordinator and Department Task Manager are necessary prior to District submittal.

Preparation of as-builts shall be in accordance with the most recent version of the CADD Users Manual (www.dot.ca.gov/hq/oppd/cadd/usta/caddman/default.htm). As presented in the CADD Users Manual, as-built plans shall include revisions to alignments and right-of-way, grade revisions, drainage changes, changes to roadway features, and revisions in location of utility crossings and irrigation crossovers. Minor feature changes (such as grade revisions less than 30 mm) and actual construction quantities are typically not reflected in as-built drawings. The Caltrans Construction Manual requires the as-builts to be completed within 60 days of contract acceptance.

6.2.2 Construction Report, WBS 295.25

The Construction Report is prepared following the completion of construction and documents the differences between what was designed and what was constructed. This documentation is necessary to capture important changes that were made in the field that could affect OM&M activities or future pilot projects.

The Construction Report should include a discussion of the following topics:

- Changes to the plans (reflected in the as-builts).
- Changes to the special provisions (e.g., material substitutions).
- A summary of CCOs (for Standard and CCO projects).
- A summary of construction costs.

- Revisions to the siting and design criteria presented in the Site Selection TM and the Design Report.
- Construction deviations that impact the Study Plan (based on review of revisions to siting and design criteria).
- Construction lessons learned (refer to Section 8.4.4 for details).
- Construction site visit reports and as-builts.

Actual construction costs incurred for the pilot study, obtained from the contractors' invoices and related material quantities, shall be reported and presented in a tabular format. The construction cost items shall be broken down by those items included in the original bid schedule, additional items of work authorized following contract award (e.g., change orders), and state-furnished materials (e.g., biofilter sod). Monitoring costs – costs required for stormwater sampling, monitoring, equipment, and facilities – shall also be included but separated from costs for the construction of the BMPs. Actual construction costs are typically presented for the following categories

- Bid Item Description
- Bid Item Quantity / Unit Cost
- Additional Work (Change Orders)
- Actual Cost
- Monitoring Costs (separate from construction costs)

Site-specific costs that are unique to the pilot study, such as the use of stormwater pumps, the inclusion of guardrails, or unique stormwater sampling/monitoring systems, shall be reported separately from the actual construction costs. Other site-specific costs may include items such as location, limited space, utility conflicts, dewatering, and others.

Draft and Final versions of the Construction Report shall be prepared. The Draft should be submitted within two months of completion of construction, and the final version would be submitted in accordance with an agreed upon review period schedule. The specific format of the Construction Report shall follow the outline provided in Appendix E.

6.2.3 Certificate of Environmental Compliance WBS 295.35

The purpose of the CEC is to document the Department's environmental compliance efforts (WBS 295.35) at CCA for all measures specified in final environmental (or other project) documentation, including permits and agreements, and inform all project stakeholders, including regulatory agencies, as to the outcome of the Department's environmental commitment measures.

The information contained within this Certificate should be based on the ECR. This Certificate, along with the updated ECR, should be filed in the Uniform File System and a copy retained in the project history file as evidence that the Department has met its obligations to fully document environmental compliance efforts for projects. For additional information, see the Department Workplan at http://www.dot.ca.gov/hq/projmgmt/documents/wsg/workplan_standards_guide_9.1.doc, and the SER, Volume 1, Chapter 39 at http://www.dot.ca.gov/ser/vol1/sec5/ch39impc/chap39.htm#a8.

6.3 Typical Timeline

A typical timeline for the construction process for the A-E Contract Delivery Method is presented in Figure 6-3. The format and representations of the timelines are the same as that described for the design process. Depending on the complexity of the project, the construction phase may take anywhere from 14 to 52 weeks.

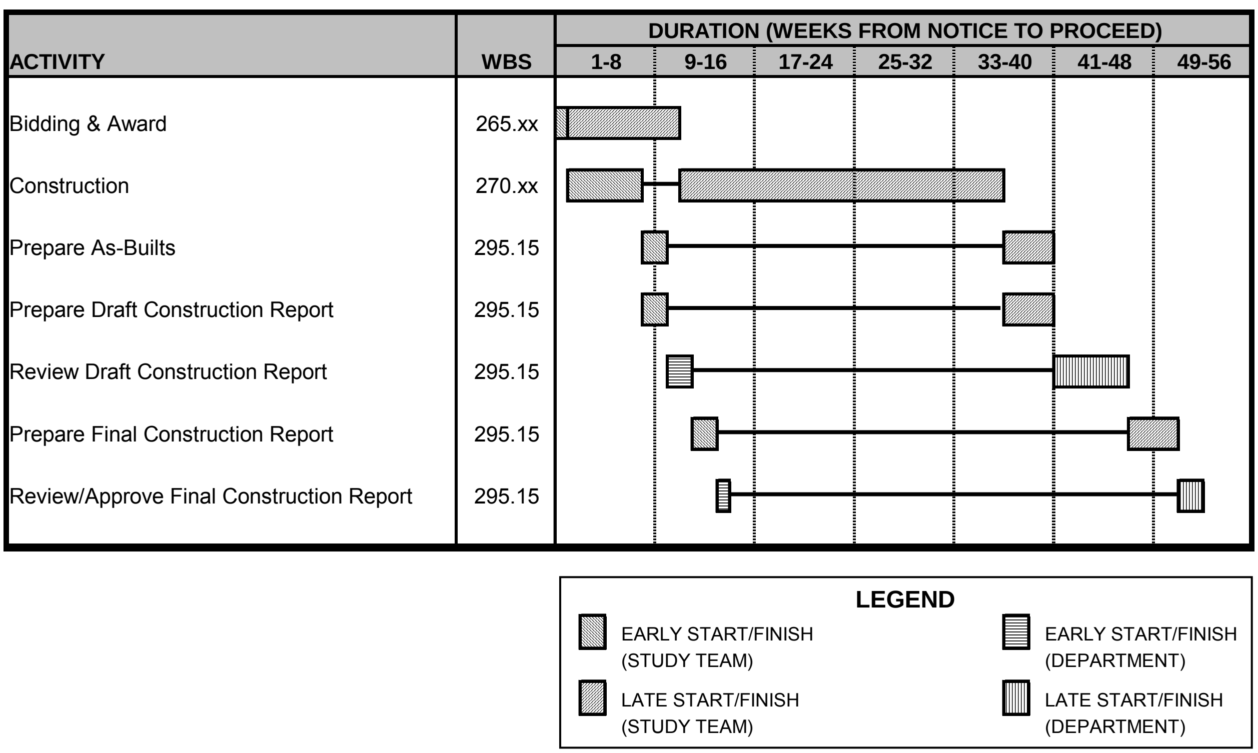

Figure 6-3 Typical Pilot Study Construction Timeline

6.4 Task Order Development

Unless directed otherwise by the Department Task Manager, task orders for construction activities should include, at a minimum, the scope elements outlined in Figure 6-4.

Scope Element	WBS	Brief Description	Deliverable(s)
Project Management	100.xx	Administration, Coordination, Scheduling, and Quality Control	Meeting Minutes Monthly Progress Reports Invoices
Construction	270.20	Construction/Installation of pilot facilities	SWPPP (or WPCP) Lead Compliance Plan (if ADL present) ADL Excavation & Disposal Plan (if ADL present) Pilot Facilities
Construction Administration	270.25	Administration of Construction/Installation tasks	Pre-Construction Meeting Minutes Notice of Construction (if SWPPP used)
Construction Inspection	270.30	Oversight and inspection of construction activities to ensure compliance with contract documents	Daily Construction Reports Redline Markups
Contract Acceptance	295	Acceptance of construction activities and preparation of final documents	Pre-final inspection Punch List Notice of Completion of Construction (if SWPPP used) Contract Acceptance Form As-Builts Construction Report Certificate of Environmental Compliance

Figure 6-4 Construction Task Order Scope Elements

Chapter 7 Operation, Maintenance, and Monitoring

The success of a BMP pilot study is directly related to the proper implementation of maintenance and monitoring procedures. Figure 7-1 shows the sequence of steps necessary to execute a BMP pilot study. Tasks in which District NPDES Coordinator involvement is recommended are identified with an "*". During the course of the study, or when the report is produced, it may be determined that the maintenance frequency and associated activities need to be adjusted from those that were pre-planned for the pilot study (i.e., Maintenance Threshold Indicators). Regular inspection and maintenance of BMPs are necessary to facilitate consistent performance and increase the likelihood of meaningful pilot study results.

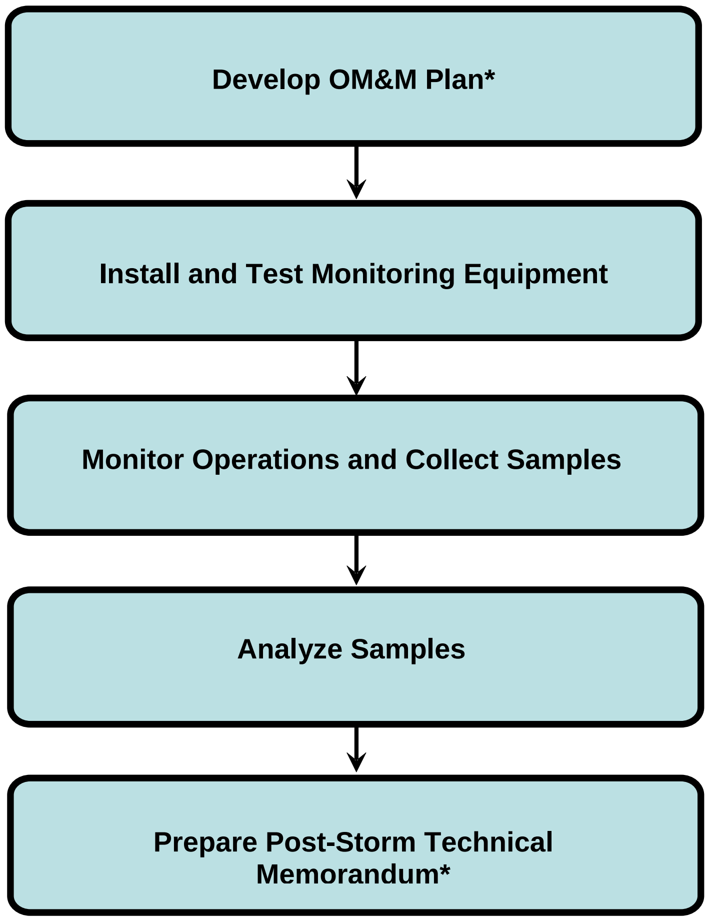

Figure 7-1 BMP Pilot Study Implementation Sequence

Conditions such as erosion, vegetation height, trash, and sediment build-up may directly affect the performance of a BMP. Likewise, good monitoring procedures will result in more reliable data.

Prior to the start of pilot study monitoring, an OM&M Plan must be prepared that defines the procedures to operate, maintain, and monitor the BMP(s) in the study. The Caltrans Comprehensive Protocols (Caltrans 2003a) and the Study Plan TM form the basis for the development of the OM&M Plan. Also, the Design Report and Construction Report should be reviewed before the OM&M Plan is developed so that the final site characteristics are established and deviations from the Study Plan are identified. The OM&M Plan acts as a bridging document between the Study Plan and the day-to-day operations of the pilot study. It shall be a practical document that clearly defines operating procedures. Adherence to the OM&M Plan by the PDT assures that procedures are consistent and documented throughout the study. This is often a critical issue in the interpretation of study results.

The OM&M Plan typically includes:

Cost Reduction Strategies $

✓ Include vector-control features in design and OM&M Plans.

- Study Objectives
- Health and Safety Plan (HSP)
- Site Description and BMP Features
- Vector Management (if appropriate)
- Operation and Maintenance
    - Routine Inspection and Maintenance Requirements
    - Maintenance Threshold Indicators
    - Operation and Maintenance Costs
- Stormwater Monitoring and Analysis
- Toxicity Testing Plan (if appropriate)

The OM&M Plan needs to be reviewed and approved by the Caltrans Task Order Manager before it is executed. Appendix F includes preparation guidelines and an outline of an OM&M Plan. More detailed information regarding the monitoring elements of the BMP pilot study is provided in the Caltrans Comprehensive Monitoring Protocols Guidance Manual (Caltrans 2003a).

7.1 Study Objectives

The study objectives in the OM&M Plan shall be consistent with the study objectives described in the Study Plan TM. If the objectives are revised from those developed in the Study Plan TM, provide an explanation of why they were modified.

7.2 Health and Safety

As part of the OM&M Plan, the health and safety of personnel involved in the monitoring program must be considered and a high priority. Persons accessing the site for operations, maintenance, and monitoring must adhere to the requirements of the HSP. Highway BMPs in particular may be placed in challenging locations and planning for human health and safety is a top priority. Some potential considerations include:

- Traffic hazards.
- Wet and possible cold weather conditions.
- Physical obstructions that complicate access to the site and sample collection point (e.g., steep slopes, vegetation overgrowth).
- Confined spaces (e.g., manholes that might contain toxic, explosive, or otherwise unsafe conditions).
- Flooding and fast moving water.
- Dim lighting.
- Slippery conditions.
- Contact with water that could be harmful (e.g., caustic, pathogenic).
- Lifting and carrying heavy and bulky pieces of equipment, including carboys and sample bottles filled with water.

Based on the hazard assessment, the appropriate equipment and procedures to protect field personnel from the potential hazards must be included in the OM&M Plan. Consider adjusting monitoring locations and/or methods, if necessary, to minimize the risk of health and safety problems. Refer to Section 6 of the Caltrans Comprehensive Monitoring Protocols Guidance Manual (Caltrans 2003a) for guidance in preparing a HSP. The HSP shall be an appendix of the OM&M Plan.

7.3 Site Description and BMP Features

Key elements on how to describe the site location, access, and BMP features are described in the following sections. This information must be included in the OM&M Plan.

7.3.1 Site Location and Access

The location and access to the BMP pilot study site must be provided so that field personnel can easily and safely access the site. Site-specific information that is important for field personnel to know about include:

- Coordination with appropriate Caltrans personnel;
- Caltrans Monitoring Site ID;
- Location and Post Mile, with site map;
- Driving directions from the Caltrans District office;
- City or County jurisdiction;
- Regional Water Quality Control Board jurisdiction;
- Parking location;
- Traffic control requirements;
- Gates, locks, keys, combinations;
- Sensitive habitat or species;
- Safety considerations;
- Other features of the site, including distance from roadway(s), slopes, ground cover, overhead concerns, etc. (include photographs of the site);
- Notification requirements; and
- Other requirements that may be specified in an EP.

Include photographs of the site and site plans/location maps, where possible.

7.3.2 BMP Features

The BMP features and monitoring appurtenances shall be described. These features will ultimately be logged as data elements in the Caltrans database. Refer to the EPA/ASCE document titled Task 1.1 – National Stormwater BMP Data Elements (www.bmpdatabase.org/docs/dataelement.pdf) for BMP features that shall be summarized. Additionally, any plans or schematics necessary to show the BMP features shall be presented. An example of a BMP schematic is shown in Figure 7-2.

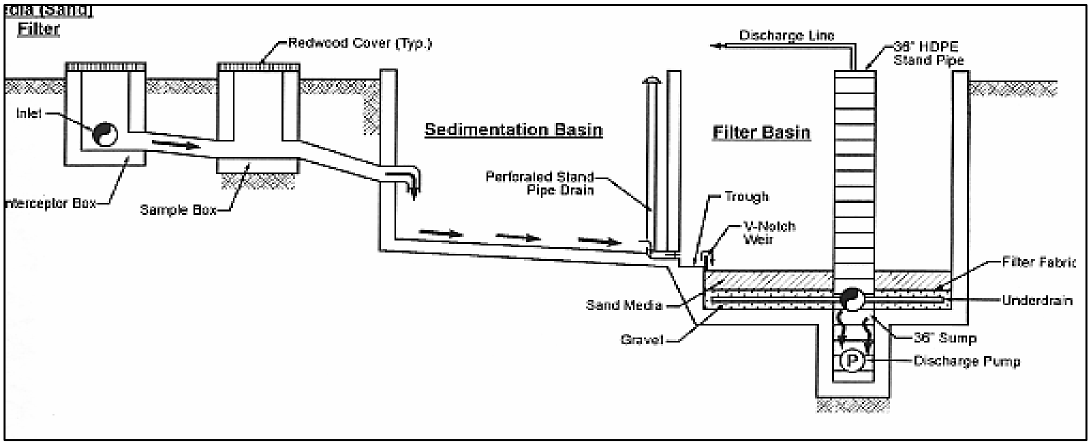

Figure 7-2 Example of BMP Schematic

7.4 Operation and Maintenance

Most, if not all, BMPs require routine maintenance, and an inadequate attention to schedule poses a high risk of operative failure. Maintenance of BMPs shall include regular inspections and, if necessary, removal of accumulated pollutants. The requirements vary from system to system, but the end result shall always be to operate and maintain the BMP under a maintenance schedule similar to what the BMP might normally receive in a typical, real-world application.

It is important that the PDT discuss the project with District maintenance so there is a clear understanding of who will handle maintenance issues; however, the PDT may have to perform some equipment specific maintenance.

> ***Examples from the Files ....***
>
> For the Caltrans Roadside Vegetated Treatment Site (RVTS) Study, it was important that Caltrans consultants coordinate with District maintenance. Caltrans consultants wanted District maintenance to continue with their routine activities (e.g., mowing). As a result, the consultants needed to track District maintenance's activities to determine their influence on the study.

In general, the frequency of BMP maintenance depends on the pollutant loading rate and the ability of the BMP to remove and retain these pollutants. Most factors that influence pollutant loading rates are site-specific, such as erodibility of native soils and landscaping materials, land-use activities, and flow dynamics. Storage capacity is also a significant factor affecting maintenance frequency.

There may be occasions where emergencies, such as accidents, spills, or other incidents arise, when critical response is needed and non-routine maintenance is required. On those occurrences, Caltrans crews will respond accordingly, and, if necessary, the BMP may be taken out of service until its functionality can be restored.

7.4.1 Routine Inspection and Maintenance Requirements

Routine or preventive maintenance refers to procedures that are performed on a regular basis to keep the BMP aesthetic and in proper working order. Routine maintenance may include removing debris, removing silt and sediment, and clearing vegetation around flow control devices to prevent clogging. Sediment and debris removal is also important to ensure monitoring equipment will function properly. Routine maintenance also includes the maintenance of a healthy vegetative cover. Dead turf or other unhealthy vegetative areas will need to be replaced or restored. If the BMP has battery-operated components, the batteries may need to be recharged or replaced. Connections, fittings, valves, joints, screws, and other mechanical parts may need to be adjusted, repaired, or replaced. BMPs with chemical additives may require removal of spent materials and/or addition of new chemicals.

Inspections shall be performed at regular intervals to ensure that the BMP is operating as designed. At a minimum, an annual inspection shall be considered but additional inspections following storm events may be appropriate, depending on the design on the BMP and the study goals. For inspections following a major storm, the Inspector shall attempt to observe whether the BMP is properly passing, retaining, or infiltrating water, and whether the pollutant storage capacity has been exceeded.

Example visual observations during a routine inspection include checking:

- Accumulation of debris and sediment at the inlets and outlets;
- Side slopes for signs of erosion, settlement, slope failure, or vehicular damage;
- Emergent vegetation zones to ensure that water levels are appropriate for vegetative growth;
- Whether vegetative cover is above acceptable limits; and
- Whether the water level is where it should be.

Non-routine or corrective maintenance refers to rehabilitative activities that are not performed on a regular basis. Examples include flow control structure replacement and the major replacement and cleaning of aquatic vegetation.

7.4.1.1 Erosion and Structural Repair

Areas of erosion and slope failure should be repaired and reseeded (or sodded) as soon as possible. However, use of compost or fertilizers shall be reviewed by the Caltrans Task Order Manager to ensure that the materials used do not impact the study results. Eroded areas near the inlet or outlet of the BMP may also need to be lined with riprap. Major damage to the inlet, outlet, or other structures shall be repaired immediately. Delay in such repairs can cause structural failure. When that occurs, the BMP may require total reconstruction, resulting in delays, cost overruns, and potential invalidation of the pilot study. Damage to inlets and outlets can also affect the proper operation of the BMP, biasing the study results.

7.4.1.2 Debris and Litter Removal and Control

Debris and litter accumulate mostly near the inlet and outlet structures of BMPs and need to be removed when they threaten the proper operation of the BMP. Particular attention shall be paid to floatable debris that can clog the outlet control structure or riser. Trash screens or trash racks can be strategically placed near inflow or outflow points to capture debris and assist with maintenance.

Litter and debris from illegal dumping shall also be cleaned up immediately. An accurate log shall be maintained of all the materials removed and improvements made. Controlling illegal dumping is difficult, although posting signs with a phone number for reporting a violation in progress may help. Notice of enforcement and substantial penalties for illegal dumping and disposal could also be a deterrent.

7.4.1.3 Sediment Removal and Disposal

Silt and other sediment removal activities can often require many laborers and heavy equipment over several days. Sediment needs to be removed on a regular schedule but as noted earlier, the frequency of removal is site-specific. Regular inspections will reveal how often sediment must be removed.

7.4.1.4 Mowing

Side slopes, embankments, emergency spillways, and other grassed areas of BMPs must be periodically mowed to control weeds and prohibit woody growth. Mowing can constitute a large portion of the routine maintenance expense. Any materials used to control weeds and prohibit woody growth shall be reviewed by the Caltrans Task Order Manager to ensure that adverse impact to the study results does not occur.

7.4.1.5 Nuisance Control

Standing water or soggy conditions in a study area or BMP can create nuisance conditions for nearby residents. Odors, vectors, weeds, and litter can be potential problems. Regular maintenance to remove debris and ensure BMP functionality will help control potential nuisance problems.

7.4.1.6 Vector Management

If the BMP being studied creates standing water, disease-carrying organisms such as insects (mosquitoes and midges) and rodents may have to be monitored and controlled. In such an instance, there will be a need to contract with local Vector Control Districts (VCDs) for inspection and abatement. Records shall be kept of the frequency of inspections, the number of insects observed, and the abatement activities performed.

The strategy for the management of potential vector problems requires the following:

- Minimize the opportunities for such vector or nuisance organisms to become a potential problem.
- Develop a monitoring and maintenance program based upon defined and regular observations and inspections that will ensure that unsuitable conditions do not develop that encourage a vector or nuisance problem.
- Define threshold criteria to identify such a problem, and treatment guidelines to correct the problem.

An example vector management plan can be found in the Caltrans BMP Retrofit Pilot Program, Final Report, Appendix E (Caltrans 2004a).

7.4.2 Maintenance Threshold Indicators

It is paramount, for consistency in operations, to develop specific thresholds for conditions which “trigger” maintenance activities. The thresholds shall be determined before the start of the study. Maintenance activities must be defined for those times when the field measurement exceeds the maintenance indicators. These thresholds and associated maintenance activities shall be based on existing technical literature and vendor-specific recommendations. For those BMPs that are not designed to contain standing water, regular inspections and maintenance activities shall be planned to prevent the incidental formation of pools. For example, trash shall be removed if it collects water. Again, records shall be kept of the type and frequency of the performance of maintenance activities.

The PDT should prepare a table of BMP Inspection and Maintenance Requirements to summarize specific thresholds that trigger maintenance activities for the study BMP. Include the following information:

- *Design Criteria*, *Routine Actions* – Specific aspect of the BMP subject to inspection and maintenance (e.g., vegetation, battery voltage, sediment, standing water).

- *Maintenance Indicator* – Field measurement threshold that indicates the need for maintenance activities (e.g., average vegetation height greater than 18-inches; battery voltage drops below 11 volts; more than 85 percent of total volume filled with accumulated material; standing water for more than 72 hours; evidence of erosion; wet season has ended).
- *Field Measurement* – Description of field measurement required to verify condition (e.g., visual observation; measure depth at apparent maximum and minimum accumulation of sediment and calculate average depth).
- *Measurement Frequency* – Frequency of inspection that potentially triggers maintenance (e.g., annually; 72 hours after a target storm event; prior to beginning of the rainy season and monthly during the rainy season).
- *Maintenance Activity* – Action that is needed when observed conditions exceed the Maintenance Indicator.
- *Site-specific Requirements* – Description of any unique site inspection and maintenance requirements.

Examples of maintenance indicators and maintenance activities are shown in Figure 7-3.

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DETENTION BASINS OPTIMIZATIONS					
DESIGN CRITERIA, ROUTINE ACTIONS	**MAINTENANCE INDICATOR**	**FIELD MEASUREMENT**	**MEASUREMENT FREQUENCY**	**MAINTENANCE ACTIVITY**	**SITE SPECIFIC REQUIREMENTS**
Basin vegetation	Average vegetation height greater than 18-inches, emergence of trees or woody vegetation	Visual observation and random measurements throughout the side slope area	Once during wet season, once during dry season	Cut vegetation to an average height of 6-inches and remove trimmings only if there is the potential to interfere with BMP outlet performance	Remove any trees or woody vegetation
Inspect for standing water	Standing water for more than 72 hours	Visual observation	Annually, 72 hours after a target storm (0.25 in) event	Drain facility, check and unclog clogged orifice; notify Caltrans Project Coordinator, if immediate solution is not evident	None
Inspection for sediment management and characterization of sediment for removal	Sediment fills 10 percent of basin volume or exceeds 18 inches in depth (evaluate marker on staff gauge)	Measure depth at apparent maximum and minimum accumulation of sediment; calculate average depth	Annually	Remove and properly dispose of sediment; regrade if necessary	None
Inspect for burrows	Burrows, holes, mounds	Visual observation	Annually and after vegetation trimming	Where burrows cause seepage, erosion and leakage, backfill firmly	None
Inspection for trash and debris	Debris/trash present	Visual observation	During routine trashing, per District schedule	Remove and dispose of trash and debris	None
Slope stability	Evidence of erosion	Visual observation	October each year	Contact the Caltrans Project Coordinator to determine the most appropriate erosion control method	None
General Maintenance Inspection	Inlet structures, outlet structures, side slopes or other features damaged, significant erosion, graffiti or vandalism, fence damage, etc.	Visual observation	Semi-annually, late wet season and late dry season	Corrective action prior to wet season; consult Caltrans Project Coordinator if immediate solution is not evident	None
Outlet Skimmer					
Inspect for clogged orifices in skimmer	Clogged orifice	Visual observation	72 hours after a target storm	Unclog the orifice	None
Inspect the skimmer connections	Loose hose connections	Visual observation	72 hours after a target storm	Tighten/repair the connection	None

Figure 7-3 Example Maintenance Indicator Thresholds (Detention Basin Optimization Study)

DETENTION BASINS OPTIMIZATIONS					
DESIGN CRITERIA, ROUTINE ACTIONS	**MAINTENANCE INDICATOR**	**FIELD MEASUREMENT**	**MEASUREMENT FREQUENCY**	**MAINTENANCE ACTIVITY**	**SITE SPECIFIC REQUIREMENTS**
Verify that skimmer floats	Skimmer below water line	Visual observation	During storm (or immediately after target storm)	Consult Caltrans Project Coordinator	None
Inspect for sediment between float valve and orifice plate	Sediment found between float valve and orifice plate	Visual observation	Just prior to start of rainy season	Remove sediment from between float valve and orifice plate	Applicable to 808R
Inspect the lever connections of the lever operated flap valve outlet	Loose or broken connections	Visual observation	Just prior to start of rainy season and 72 hours after a target storm	Repair any loose or broken connections	Applicable to 859L
Hold and Release Valve (Air Operated Valve Outlet)					
Check pressure in compressed air tank	Pressure less than 80 psi	Visual observation of pressure gauge	72 hours after a target storm, at beginning of rainy season and monthly during the rainy season	Add compressed air to tank to achieve a pressure of 120 psi	Applicable to 457L and 535L
Check all electrical connections tightness and corrosion	Loose or corroded connections	Visual observation	Just before the rainy season	Tighten, clean and replace as necessary	Applicable to 457L and 535L
Check battery voltage	Battery voltage drops below 11 volts	Measure battery voltage with voltage meter	72 hours after a target storm, at beginning of rainy season and monthly during the rainy season	Recharge or replace battery to 12 volts	Applicable to 457L and 535L
Check timing cycle for proper operation	Timer initiates valve closing and holds valve closed for specified timer period	Manually initiate operation and visually check valve operation	Just before the rainy season	Reset timer if necessary; repair and replace if necessary	Applicable to 457L and 535L
Exercise the valve and ensure that the valve closes tight	Valve does not close tight	Visual observation	Just prior to start of rainy season	If air pressure is sufficient, check to ensure solenoid valve is operating and repair as necessary; if solenoid valve is operating, check to determine if rubber liner needs to be replaced and replace if necessary (refer to Appendix G)	Applicable to 457L and 535L

Figure 7-3 Example Maintenance Indicator Thresholds (Detention Basin Optimization Study) (Continued)

7.4.3 Equipment and Tools Needed

The PDT should identify equipment and tools that are needed by inspection and maintenance personnel. Checklists may include, but are not limited to:

- Locke level or survey equipment
- Tape measure or other measuring device
- Flashlight
- Maintenance equipment and tools
- Rain gear
- Safety equipment, including personal protective equipment (PPE)
- Traffic control devices
- Inspection forms and logbook; pen or pencil
- Encroachment Permit
- Business cards or other identification
- Camera

7.4.4 Checklists for Inspectors and Maintenance Personnel

The PDT should provide Site Inspection and Site Maintenance Forms to ensure consistent BMP operation and maintenance in conformance with routine inspection and maintenance requirements.

- Site Inspection Forms shall include:
  - Date and time of inspection
  - Inspector name
  - List of all aspects of the BMP subject to inspection and maintenance
  - Cue for required Field Measurements, with reference to Maintenance Indicator Thresholds
  - Description of photographs
  - General site observations

- Site Maintenance Forms shall include:
  - Date and time of maintenance work
  - Supervisor name
  - List of specific maintenance activities
  - Start, end, and total time and resources used for each activity
  - Status of completion of each activity
  - Comments

Operations and Maintenance (O&M) Field Logs should be maintained to record all site visits, inspections, and maintenance activities.

7.4.5 Operation and Maintenance Costs

This section specifically focuses on the types of operation and maintenance cost data that must be collected throughout the pilot study. These data are important for evaluating the cost effectiveness of the BMP, and for estimating future life cycle costs for potential installations. As shown in Figure 7-4, life cycle costs include original construction, regular and irregular maintenance, and major rehabilitation or reconstructing at the end of the design life.

Typical costs associated with O&M of a BMP include labor, equipment, materials, tools and utilities. During the pilot study, actual costs for operation and maintenance need to be tracked.

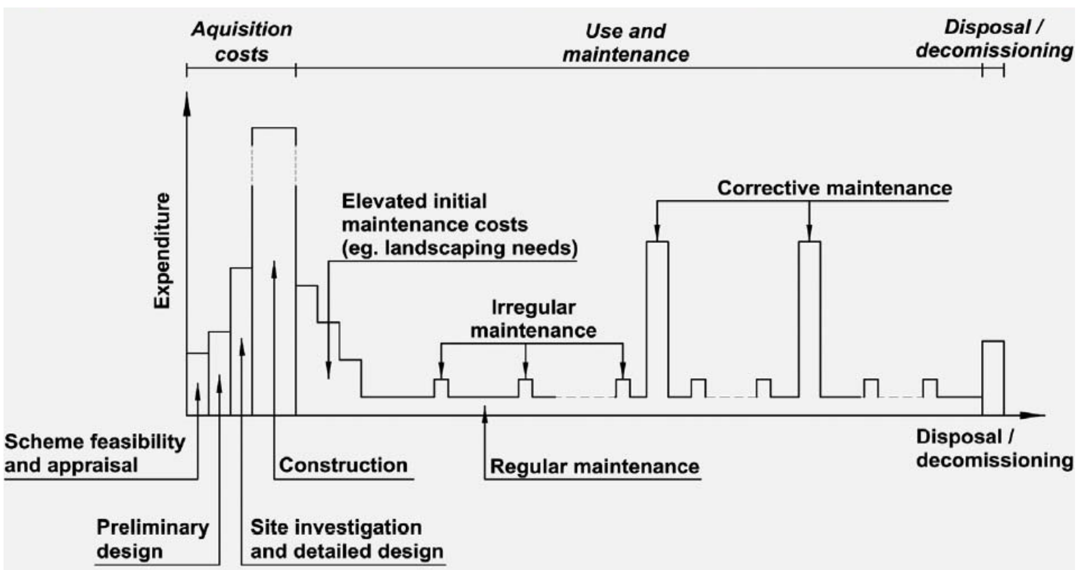

Figure 7-4 BMP Life Cycle Costs

O&M costs go hand-in-hand with effort needed to keep the BMP functioning (i.e., effort needed to perform activities that are triggered by maintenance thresholds). Forms shall be developed for the OM&M Plan. The forms shall include sections that allow the inspection and maintenance teams to track the hours and direct costs for each inspection and maintenance activity performed. Costs can be categorized as administrative, operation and maintenance, vector control, equipment, and direct costs associated with operation and maintenance. All costs except administrative define the total operation and maintenance cost. Described below is each cost category:

- *Administrative costs* are comprised of general program support/follow-up, EPs, travel, and unscheduled events. Travel costs include labor and equipment hours to and from the study site for inspection and maintenance. Costs for unscheduled events include office time to support equipment break-downs, power outages, or storm events.
- *Operation costs* are related to labor and equipment hours used for inspection and field calls. Scheduled inspections include wet season and dry season inspections of the BMP. Unscheduled inspections needed to evaluate the BMP are also included.
- *Maintenance costs* shall be categorized under the sub-headings of scheduled and unscheduled maintenance, vandalism, acts of God, and landscape maintenance. Scheduled and unscheduled maintenance costs can include irrigation, removal of standing water, removal of sediment, removal of trash, removal of debris, landscape management, management of structural integrity, pump servicing, cleaning of filters, and graffiti removal. Acts of God include costs for repairs to the BMP caused by severe weather, earthquakes, or other extreme acts of nature.
- *Vector control costs* include vector control and abatement and office work related to contracting VCDs.
- *Equipment costs* are associated with the time a piece of equipment is used for BMP maintenance.
- *Direct costs* are associated with VCD supplies, reproduction and postage, field supplies and minor equipment (shovels, gloves, etc.), miscellaneous equipment rental, sediment analysis, sediment disposal, and miscellaneous other direct costs.

Tracking these costs are important for a number of reasons, including evaluating the cost-benefit of a BMP, budgeting future BMP O&M cost expenditures, tracking the level of effort during the year to determine when peak staff effort is required, and for identifying opportunities to adjust maintenance activities. Figure 7-5 is an example of an Operation and Maintenance Cost Accounting Summary Form.

DISTRICT: 7	LOCATION: I-605/Carson & Del Amo Avenue	SITE NO. 73255	BMP TYPE: Biofiltration Swale	CONSULTANT: Montgomery Watson - Chaudhary

	TASK	1999							2000					
		Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	(hrs)	Rate	TOTAL $
Labor (hours)	***Administration***													
	General program support/Follow-up	3.0	5.8	8.0	4.8	3.3	7.0	9.3	7.3	4.5	15.4	68.2	$120	$ 8,184
	Encroachment Permits											0.0	$87	$ -
	Travel	2.7	3.8	15.4	32.4	37.0	5.1	5.5	6.8	6.4	8.6	123.6	$87	$ 10,753
	Unscheduled events		1.0	8.3	1.0							10.3	$87	$ 892
	Monthly Subtotal (hours)	5.7	10.6	31.6	38.1	40.3	12.1	14.8	14.1	10.9	24.0	202.0		
	Monthly Subtotal ($)	$591	$1,114	$3,013	$3,471	$3,609	$1,278	$1,595	$1,465	$1,097	$2,597	$19,828		
													Task Subtotal =	$19,828
	Operation													
	Wet season inspections					1.0	0.5	1.5	0.8	1.3	1.5	6.5	$55	$ 358
	Dry season inspections	0.5	1.0	0.5	1.0							3.0	$55	$ 165
	Unscheduled inspections/field calls								1.0			1.0	$60	$ 60
	Monthly Subtotal (hours)	0.50	1.00	0.50	1.00	1.00	0.50	1.50	1.75	1.25	1.50	10.50		
	Monthly Subtotal ($)	$28	$55	$28	$55	$55	$28	$83	$101	$69	$83	$583		
													Task Subtotal =	$583
	Maintenance													
	Scheduled maintenance	1.5	1.0	0.5	5.0	11.0		14.5	6.3	6.8	3.5	50.0	$55	$ 2,750
	Unscheduled maintenance			38.3	46.0	33.8	10.0	6.0				134.0	$55	$ 7,370
	Vandalism											0.0	$55	$ -
	Acts of God											0.0	$55	$ -
	Landscape Maintenance Contractor											0.0	$0	$ -
	Sediment Removal Contractor											0.0	$0	$ -
	Vegetation Consultant					0.9	0.9	3.0	1.2			5.9	$75	$ 445
	Other Contractor											0.0	$0	$ -
	Other Contractor											0.0	$0	$ -
	Monthly Subtotal (hours)	1.50	1.00	38.75	51.00	45.62	10.90	23.50	7.41	6.75	3.50	189.93		
	Monthly Subtotal ($)	$83	$55	$2,131	$2,805	$2,527	$618	$1,353	$431	$371	$193	$10,565		
													Task Subtotal =	$10,565
	Vector Control													
	Contract & General administration	1.0	1.3	1.0	0.3				0.1	0.1	0.1	3.9	$120	$ 462
	Vector prevention maint. (consultant)											0.0	$65	$ -
	Response to VCD calls (consultant)											0.0	$55	$ -
	VCD efforts (contracted)	6.2	9.7	8.1	6.5	5.5	5.1	8.0	5.6	6.4	5.0	66.2	$46	$ 3,074
	Monthly Subtotal (hours)	7.20	10.99	9.13	6.75	5.45	5.10	8.04	5.71	6.52	5.13	70.02		
	Monthly Subtotal ($)	$408	$606	$498	$332	$253	$237	$373	$273	$310	$246	$3,536		
													Task Subtotal =	$3,536
Non-Recurring Equipment (hours)	***Equipment***													
	Water Tank with Pump			38.3	46.0	33.8	10.0	6.0				134.1	$5	$ 670
	Weed Wacker					2.0						2.0	$5	$ 10
	Piece of Equipment 3											0.0	$0	$ -
	Piece of Equipment 4											0.0	$0	$ -
	Piece of Equipment 5											0.0	$0	$ -
	Piece of Equipment 6											0.0	$0	$ -
	Monthly Subtotal (hours)	0.00	0.00	38.25	46.00	35.80	10.00	6.00	0.00	0.00	0.00	136.05		
	Monthly Subtotal ($)	$0	$0	$191	$230	$179	$50	$30	$0	$0	$0	$680		
													Equipment Subtotal =	$680

	Direct Costs	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	**Total $**
Dollars ($)	VCD supplies (direct costs less labor)											$ -
	Reproduction	$ 8	$ 9	$ 13	$ 5		$ 2	$ 1	$ 1	$ 1	$ 4	$ 44
	Postage/FedEx	$ 8	$ 9	$ 13	$ 5		$ 3	$ 1	$ 1	$ 2	$ 4	$ 45
	Lodging			$ 5		$ 9		$ 15			$ 7	$ 35
	Per Diem			$ 3		$ 6		$ 10			$ 3	$ 22
	Incidentals	$ 8	$ 9	$ 13	$ 5		$ 10	$ 1	$ 1	$ 7	$ 18	$ 71
	Vehicle Rental/Lease	$ 50	$ 74	$ 65	$ 10	$ 11	$ 24	$ 48	$ 113	$ 110	$ 6	$ 511
	Airfare											$ -
	Field Supp./Expendables	$ 10	$ 1	$ 3	$ 1	$ 24	$ 3	$ 3		$ 4	$ 9	$ 58
	Equipment Rental											$ -
	Sediment Analyses											$ -
	Sediment Disposal											$ -
	Weed Wacker	$ 15										$ 15
	Vegetation Disposal											$ -
	Scarifying/Hydroseeding								$2,374			$ 2,374
	Storage Container			$ 4								$ 4
	Monthly Subtotal	$ 99	$ 102	$ 118	$ 25	$ 50	$ 42	$ 79	$2,491	$ 124	$ 50	$ 3,180
	MONTHLY TOTAL	$1,208	$1,932	$5,979	$6,918	$6,673	$2,252	$3,512	$4,760	$1,971	$3,167	**1999/2000 TOTAL = $38,371**

Figure 7-5 Example Operation and Maintenance Cost Accounting Summary Form

7.5 Stormwater Monitoring and Analysis

The purpose of monitoring is to obtain data to answer the study questions, which have been defined to meet the study objectives. A well-designed and carefully monitored pilot study can test components of the BMP or the BMP itself before full-scale deployment. Figure 7-6 is a graphical representation of the processes required to monitor a BMP pilot study; the process includes planning, data collection, verification, validation, and management. Refer to the Caltrans Comprehensive Monitoring Protocols Guidance Manual (Caltrans 2003a) to obtain additional detail.

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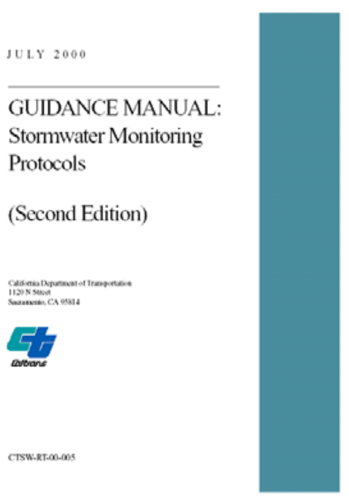
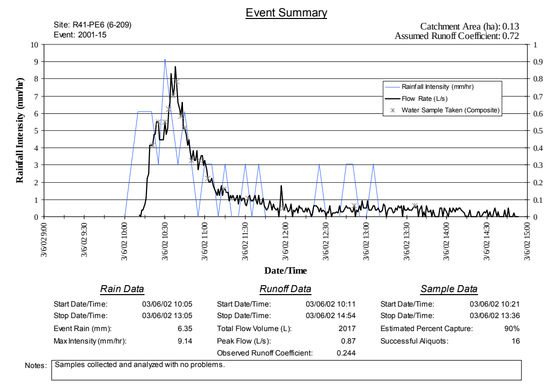




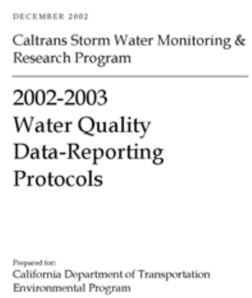
Prepare OM&M Plan

Install/Calibrate/Maintain Monitoring Equipment and Use Trained Samplers

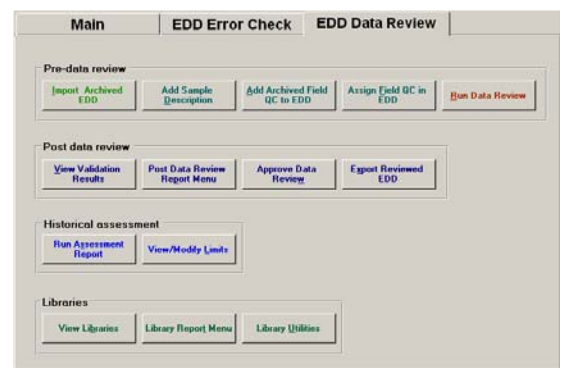
Process Time-Series Data Using Hydrology Tool

1	Run ID		Copper, Dissolved (all sites)	TPH (grab)
2	n		15	12
3	Percent detected		66.70%	75.00%
4	Mean		9.704406923	72.77827423
5	Standard	Deviation	12.13810717	30.81757517
6	Coefficient of	Variation	1.250782996	0.423444709
7	Lower 95% Confidence	Limit	3.561677167	55.34158962
8	Upper 95% Confidence	Limit	15.84713668	90.21495884
9	Lower Quartile (25th	percentile)	2.176601356	49.14055852
10	Median (50th	percentile)	6	67.44387278
11	Upper Quartile (75th	percentile)	9	92.56459661
12	Inter Quartile	Range	6.823398644	43.42403809
13	Minimum Detected	Value	4	40
14	Maximum Detected	Value	41	123
15	Minimum Reporting	Limit	1	25
16	Maximum Reporting	Limit	1	50
17	Regression	Equation	ln(y) = 1.66087884848739+ 1.30989086984014*Z	ln(y) = 4.21129573766295+ 0.46961747973838*Z
18	Note:		Bolded values are exact calculations. Unbolded values are estimated using regression on ordered statistics (ROS).	Bolded values are exact calculations. Unbolded values are estimated using regression on ordered statistics (ROS).

Perform Necessary Statistics



Prepare Post-storm Technical Memoranda



Check and Validate Analytical Data Using Caltrans EDD Checker/ADV Software

Figure 7-6 BMP Pilot Monitoring Process

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7.6 Optimize the Design for Obtaining the Data

Ideally, the systematic planning process can be iterative for each study. It is possible to modify study parameters, based on collected data and field observations, to optimize data collection to meet study objectives. This can sometimes be done during natural break points of the study (e.g., at the end of the wet season), when data are analyzed and achievement of study objectives is assessed. In some cases, the collected information may indicate the need to modify goals, collection methods, the analytical constituent list, or types/frequency of storms sampled. Interim Reports for the study shall document such recommendations (see Chapter 8).

As discussed later in this Manual (Chapter 8), Interim Reports are to be written annually for ongoing studies. At that time the Study Plan TM shall be consulted and checked against the field experience. The purpose of this check is to assure that the experimental activities are adhering to the Study Plan TM. Of particular importance is checking whether assumptions made in the Study Plan TM are proving to be true. One example is checking whether the runoff is originating from the highway or whether there is intermingling with extraneous flows. Another example might be an assumption that infiltration or some other parameter is negligible. Preliminary statistical analysis shall be performed to check the assumptions made of the variance in the data used to estimate the number of samples needed. If the actual variance is smaller than the assumed value, the study might be shortened. If the variance is larger, additional sampling may have to be done. Based on field experience, it might also be advisable to modify sample collection methods, the analytical constituents list, or the storm event criteria. Care must be exercised, however, to avoid introducing changes that interrupt the continuity of the data collection, making data collected at different times in the study incompatible. An example of this might be a decision to drop total suspended solids (TSS) in favor of turbidity as a measure of solids in the runoff. Another example might be radically changing the location or protocol of sampling. With proper caution, alternative sampling and analysis designs may improve the quality and/or cost effectiveness of the study.

7.7 Developing Monitoring Task Orders

This section is intended to provide guidance on scope elements to be included in task orders for pilot studies. Task orders shall include the key components described in Figure 7-7.

TASK	DESCRIPTION	COMPONENTS
1	Kick-Off Meeting	Discuss scope, project schedule and/or deliverable due dates, and project budget; distribute documents related to the project; introduce personnel (Caltrans and Consultant) responsible for project and establish chain-of-command for communication; discuss lessons learned; and conduct site walk.
2	Review Existing Documents	Review documents including, but not limited to, PS&Es; basis of design reports; Study Plan TM; Site Selection TM; existing permits; other relevant plans; and BMP post-construction report.
3	Obtain Permits	Obtain all permits necessary to install monitoring equipment and conduct the activities proposed for the pilot study, including encroachment and other agency permits.
4	Prepare OM&M Plan	Prepare an OM&M Plan that defines the procedures to operate, maintain, and monitor the BMP in the study (see Chapter 7).
5	Acquire Monitoring Equipment	Acquire equipment used by Caltrans previously, where available. If sufficient equipment is not available, new equipment will be purchased and distributed to the PDT.
5.1	Install Monitoring Equipment	Install monitoring equipment at approved monitoring stations. Conduct field calibration checks at the monitoring stations to ensure equipment operability after the monitoring equipment is installed.
5.2	Maintain Monitoring Equipment	Dispatch field crews to perform routine inspection, maintenance, and calibration throughout the study period. The PDT shall apprise Caltrans of major equipment and/or maintenance issues.
6	Storm Sampling	Identify number of storm events and period of monitoring. Stress the need to continuously collect time series data throughout the pilot study.
7	Operation and Maintenance of BMP	Perform maintenance of BMPs under a maintenance schedule similar to what the BMP might get in a typical deployment, in accordance with the study's OM&M Plan (see Section 7.4).
8	VCD Contracting	Contract with a Vector Control District for the inspection and abatement of vectors, if necessary.
9	Data Management	Perform laboratory data management and OM&M cost data management.
10	Post Storm Reporting	Prepare and submit for approval by Caltrans a Post-Storm TM for each sampling event. The memorandum shall include storm conditions, an assessment of the performance of the monitoring equipment, hydrographs for each monitoring station, and other records specific to the pilot study. The task order must define how the document will be submitted.
11	Equipment Demobilization	Remove the monitoring equipment from the stations at the end of the study period. Coordinate with Caltrans to move the removed monitoring equipment to the Caltrans equipment inventory.
12	Interim and Final Reporting	Submit Interim and Final Reports in accordance with the study's specified report frequency and content.
13	Project Management and Coordination	Schedule meetings with Caltrans as often as necessary to ensure that the PDT and Caltrans share a common understanding of the pilot study's and Task Order's objectives.

Figure 7-7 Monitoring Task Orders and Component Descriptions

Chapter 8 Interim and Final Reports

The results of a pilot study shall be presented in one or more Interim Reports, intended to be prepared annually at the end of the monitoring season. The appropriate report frequency and content depends on the study objectives. Interim and Final Reports must be submitted to the District NPDES Coordinator for review.

The purpose of the Interim Report is to provide the findings and status/progress of the pilot study. Information provided in the Interim Report is used to evaluate the successes or shortcomings of the Study Plan and document the tentative performance of the BMP based on limited results. The statistical approach used in the study and summarized in the report will assess if sufficient data have been collected from which to draw conclusions, or if additional data are necessary. Recommendations for improving the study shall be provided in the report. Consideration shall be given to presenting the results (data summaries, etc.) from previous reports to aid the reader in placing this study/performance in context.

The Interim Report can be used as the Final Report if the goals and objectives of the study have been achieved and no additional data need to be collected. The Final Report is usually developed at the end of several seasons of monitoring, when monitoring is complete. The Final Report includes additional information that is generally not contained in the Interim Report, such as the cost summary and detailed statistical analysis. Submittal of the Final Report also includes submittal of the collected data to the Caltrans Master Stormwater Database and ASCE International Stormwater BMP Database.

Figure 8-1 and the following sections describe the necessary components of the Interim and Final Reports. Guidelines for the preparation of typical Interim and Final Reports are presented in Appendix G.

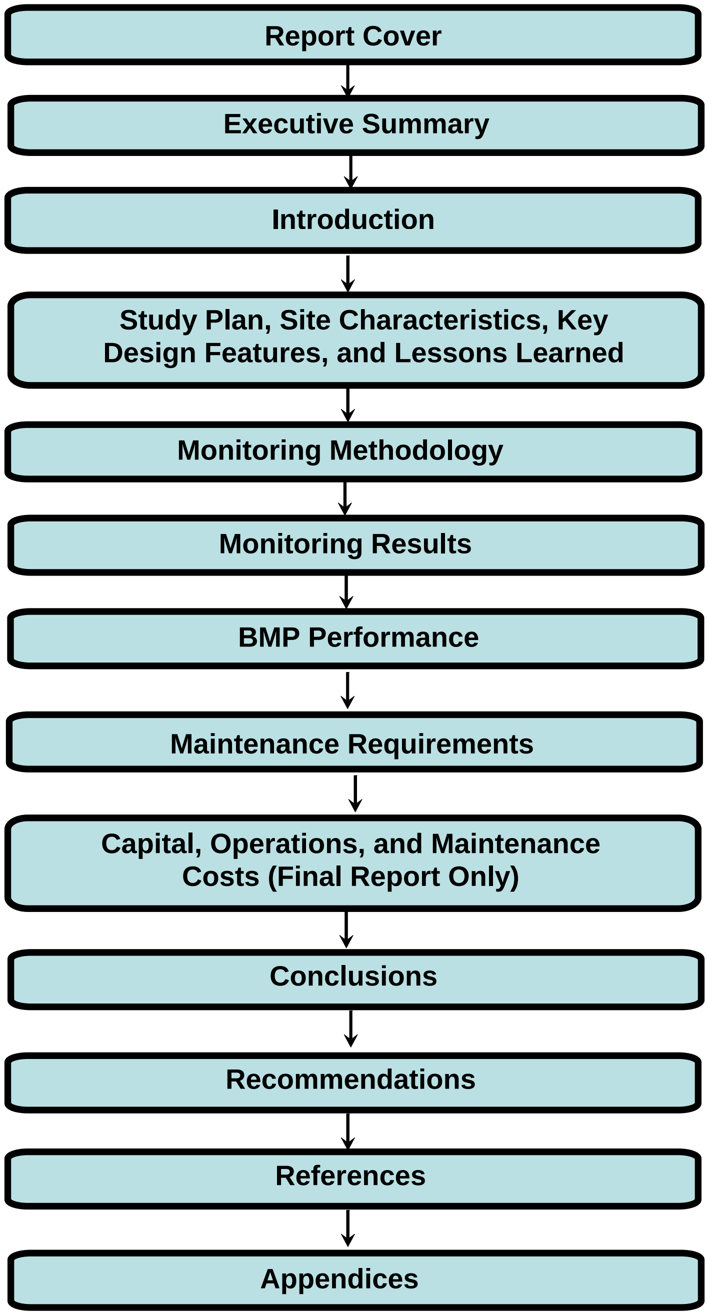

Figure 8-1 Interim and Final Report Outline

8.1 Report Cover

Reports shall include the following information on the document cover:

- Caltrans logo
- Title of report
- Report date
- Report number
- California Department of Transportation
- Division of Environmental Analysis
  - Stormwater Program
  - 1120 N Street, Sacramento, California
- http://www.dot.ca.gov/hq/env/stormwater/index.htm

The report number, or document control number, shall use the following format: CTSW-WW-YY-XXX.ZZ.1.

- "CTSW" stands for Caltrans Storm Water.
- "WW" indicates the type of document. The following report coding shall be used depending on the type of document:
  - RT (Report): Typically can be distributed to the public and may be placed on the website – such as Annual Reports and final monitoring / study reports.
  - OT (Other): Caltrans or other documents such as training manuals and CDs. Often Caltrans-specific information.
  - PL (Plans): Caltrans internal document; usually not distributed to the public or placed on the website. Items such as PS&Es; OM&M Plan; Monitoring and Operations Plan (MOP); other Plans.
  - SA (Software Application): Caltrans internal document – software developed for Caltrans Storm Water use.
  - TM (Technical Memorandum): Caltrans internal document such as an interim report, data summary, or issue paper.

> ***Helpful Hint*** **Report Number**
>
> The third report issued under contract number 43A0125 and task order number 05 in calendar year 2003 would be CTSW-RT-03-125.05.3. If the report was a draft version, the document control number would be CTSW-RT-03-125.05.D3.

- "YY" indicates the calendar year of the report.
- "XXX" indicates the last three digits of the contract number.
- "ZZ" indicates the task order number.

- The last digit is the sequential report number issued by the specific task order. A “D” in front of this digit indicates the report is a draft version.

All documents and reports that the Consultant produces shall also include the following statement: “For individuals with sensory disabilities, this document is available in alternate formats upon request. Please call or write to Storm Water Liaison, Caltrans Division of Environmental Analysis, MS 27, P.O. Box 942874, Sacramento, CA 94274-0001. (916) 653-8896 Voice, or dial 711 to use a relay service.”

8.2 Executive Summary

The Executive Summary for both the Interim and Final Reports shall provide the reader a concise overview of the pilot study, from inception through implementation, to conclusions and recommendations, such as monitoring improvements. The Executive Summary shall include the following:

- Study Background
- Study Objectives, including constituents of concern
- Study Plan (Final Report only)
- Site Characteristics (Final Report only)
- Key Design Features (Final Report only)
- Siting, Design, Construction, and Monitoring Lessons Learned (Final Report Only)
- Monitoring Activities (types of storms, number of storms)
- Summary of Results
- Power Analyses (Interim Report only)
- Statistical Analyses (Final Report only)
- Performance in terms of key constituents
- Maintenance Activities
- Maintenance Costs (Final Report only)
- Conclusions (state primary and secondary study questions and provide an answer to each question)

8.3 Introduction

The Introduction shall discuss the following items:

- Purpose of the study;
- Project overview and objectives (and if these changed from the Study Plan);
- Description of the BMP(s) evaluated;
- Study Plan; and
- Report organization.

Refer to Section G1.3 of Appendix G for guidance on how to prepare this section.

8.4 Study Plan, Site Characteristics, Key Design Features, and Lessons Learned (Final Report Only)

8.4.1 Study Plan

The Study Plan shall be provided as an appendix.

8.4.2 Site Characteristics

This section of the Final Report shall discuss site characteristics such as the size and complexity of the drainage basin(s).

8.4.3 Key Design Features

This section of the Final Report shall include information on design features such as WQVs and WQFs.

8.4.4 Siting, Design, Construction, and Monitoring Lessons Learned

This section of the Final Report presents the lessons learned throughout the siting, design, construction, and monitoring phases of the pilot project. The purpose of lessons learned is to provide a record of the experience gained by the PDT and disseminate that experience to others who may benefit from it. The lessons learned should help to promote the recurrence of desirable outcomes and minimize the recurrence of undesirable outcomes. They should draw on both positive experiences – good ideas that prevent problems and reduce costs, and negative experiences – lessons learned after an undesirable outcome has already occurred. The lessons learned should include the broad base of project experience and not be limited solely to specific areas such as data collection or safety.

General questions that shall be considered when developing the lessons learned include the following (each question may be applicable to any pilot study phase):

- What went right (i.e., as planned)?
- What went wrong (i.e., not as planned)?
- What unexpected events occurred?
- What could be done differently in the future (to save time, reduce costs, or improve performance)?
- What should be done differently in the future (to avoid delays, cost escalations, or performance problems)?
- Where were significant resources focused ineffectively?
- What areas/tasks received more attention than necessary?
- What areas/tasks need more attention in the future?

Specific lessons learned during the siting, design, construction, and monitoring phases of the pilot study are to be included in the Site Selection TM, Final Design Report (FDR), Post-Construction Report (PCR), and Post-storm Technical Memoranda, respectively. At the conclusion of the pilot study, the lessons learned from these individual documents are reviewed from an overall project viewpoint for completeness and content, and compiled for inclusion in the Pilot Study Final Report.

Lessons learned shall be grouped into one of three categories for reporting:

A: A practice promoting or resulting in a positive outcome.
B: A fact, discovery, or lesson of benefit to others.
C: An action that resulted in adverse consequences.

Sample lists of some lessons learned from past pilot studies are presented in Tables 8.1 through 8.3.

Table 8.1 Sample Siting Lessons Learned

Lesson Learned	Category
Avoid sites with potential baseflow.	B
BMP aesthetics are a significant concern in the Lake Tahoe area.	B

Category Key:
A A practice promoting or resulting in a positive outcome
B A fact, discovery, or lesson of benefit to others
C An action that resulted in adverse consequences

Table 8.2 Sample Design Lessons Learned

Lesson Learned	Category
Presenting PS&E submittals to District staff in a meeting facilitates the review process.	A
For projects with long duration construction schedules, appropriate escalation factors should be incorporated into the engineer's estimate.	B
BMP elements must be designed to support maintenance activities.	B
Non-roadway specialty items may take a long time to procure and should be taken into account when preparing the Special Provisions.	C
Do not include vegetation removal in the PS&E without prior coordination with District environmental staff.	B
Make sure to specify locally-available material to avoid procurement problems.	C
The gross solids storage area should be covered to prevent captured material from being wind-blown out of the device.	C
Erosion control materials should only be placed immediately prior to or during the wet season.	C
When using pre-cast inlets with pre-cut pipe openings, make sure the pipe invert elevations are correct.	C
As-built drawings are not always accurate and may not include all underground utilities within the project area, especially within maintenance stations.	C
It is difficult for contractors to grade the bottom of earthen basins relatively flat. A minimum slope should be specified.	C
Although District safety reviews are not typically conducted until after the 90 percent submittal, any coordination prior to that may save time.	B
Minimize use of sod as a primary means of establishing or restoring vegetation in bioswales because it results in increased project costs.	B
Install biofiltration strips at the time of the year when there is a reasonable chance of successful establishment without irrigation.	C
Following manufacturer's guidelines for installation of the Drain Inlet Inserts was inadequate for providing a tight seal between the device and the inlet frame.	C
Engaging the monitoring Consultant early in the design phase facilitated the operations and maintenance of the pilot BMP.	A

Category Key:
A A practice promoting or resulting in a positive outcome
B A fact, discovery, or lesson of benefit to others
C An action that resulted in adverse consequences

Table 8.3 Sample Construction Lessons Learned

Lesson Learned	Category
Make sure flumes installed by the Contractor are perfectly level.	B
Features built not per plan should be brought to the attention of the Resident Engineer when they are discovered and not when construction is complete.	B
Quality control during construction is critical for drainage items with minimal slopes.	C

Category Key:
A A practice promoting or resulting in a positive outcome
B A fact, discovery, or lesson of benefit to others
C An action that resulted in adverse consequences

Table 8.4 Sample Monitoring Lessons Learned

Lesson Learned	Category
Flumes were not capable of rating low flows.	C
Mobilization criteria was modified during the course of the study to minimize missed events.	A
Laboratory was unable to meet project detection limitis.	C
Customized coolers were used to prevent bottle breakage.	B
Sampler had difficulty drawing an aliquote because of its distance from the monitoring point.	B
Poor mass balance of flows between influent and effluent monitoring points.	A

Category Key:
A A practice promoting or resulting in a positive outcome
B A fact, discovery, or lesson of benefit to others
C An action that resulted in adverse consequences

8.5 Monitoring Methodology

The Monitoring Methodology section shall discuss the following items:

- Monitoring program;
- Flow and precipitation measurement;
- Sampling methods;
- Analytical methods;
- Operational methods; and
- Flow and monitoring equipment calibration.

Refer to Section G1.5 of Appendix G for guidance on how to prepare this section.

8.6 Monitoring Results

The Monitoring Results section shall discuss the following items:

- QA/QC;
- Monitored events;
- Rainfall and flow monitoring results;
- Operational monitoring results; and
- Analytical results.

Refer to Section G1.6 of Appendix G for guidance on how to prepare this section.

8.7 BMP Performance

The BMP Performance section shall discuss the following items:

- Statistical methods for data analysis;
- Summary statistics;
- Objectives and findings; and
- Performance evaluation.

Refer to Section G1.7 of Appendix G for guidance on how to prepare this section.

8.8 Maintenance Requirements

The Maintenance Requirements section shall discuss the following items:

- Maintenance indicator thresholds and any necessary changes or enhancements.
- Lessons learned on maintenance.

Refer to Section G1.8 of Appendix G for guidance on how to prepare this section.

8.9 Capital, Operations, and Maintenance Costs (Final Report Only)

Actual costs for the design, construction, operation, maintenance, and monitoring of a BMP need to be included in the Final Report. In addition, estimates of construction and O&M costs for a typical (as opposed to experimental) installation at the site shall be provided.

It is important to include an accurate estimate of the design costs in the Design Report because these costs need to accounted for in the pilot study life cycle costs, and the life cycle costs are typically developed by someone other that the design team. Design costs should be obtained from the Design Report described in Section 5.5.

Actual construction costs incurred for the pilot study, obtained from the contractors' invoices and related material quantities, shall be reported and presented in a tabular format. Actual construction costs should be obtained from the Construction Report described in Section 6.2.2.

It is important to differentiate between the costs of retrofitting a BMP and constructing a new BMP. Large portions of the costs associated with retrofitting an existing BMP may be attributed to changes in the original storm drain system to direct stormwater runoff, which is normally not a concern in new BMP construction. Construction cost reporting shall reflect these differences. In addition, according to the Caltrans BMP Retrofit Pilot Program, Final Report (January 2004a), the cost to retrofit structural BMPs is highly site-specific and does not readily lend itself to normalization for application to other studies or projects. Accurate BMP retrofit costs may best be determined with a complete unit cost estimate based on design plans for the study site.

Operation and maintenance costs tracked for the pilot study shall be summarized as previously discussed in Chapter 7. These costs include vector control and equipment and direct costs associated with operation and maintenance.

Determining an accurate cost of a BMP can help define long-term investment requirements and allow Caltrans to make more cost-effective decisions when selecting BMPs. Researchers at the Water Environment Research Foundation (WERF) developed a cost calculation model called the Whole Life Cost model to standardize a consistent approach to forecasting life cycle costs. The concept of whole-life costing grew out of recognition that the initial cost of a BMP was only one part of the total expenditure required over its lifetime. Whole-life costing is about identifying future costs, such as those associated with operation and maintenance, and relating them to present-day costs using standard accounting techniques (www.werf.org/products/tools.cfm).

Whole-life cost analysis is performed using a series of interactive spreadsheets that assemble the expenses required to construct and maintain a BMP. These spreadsheets consider factors such as design life, capital costs, routine and corrective maintenance, and discount rates. Users input data for a specific site into the spreadsheets and estimate the expected whole-life costs associated with a particular BMP. Using whole-life cost analysis, researchers at the WERF have recognized that the level of maintenance of a BMP is more important than the capital cost. To help more accurately determine expected maintenance costs for various BMPs, it is recommended that field monitoring of BMPs performance be conducted, along with diligent record keeping during operation and maintenance activities.

8.10 Conclusions

It is important to determine the significance and meaning of the results of a pilot study and what conclusions can be drawn from the results based on the collected data. Ideally, the results shall provide an indication of the effectiveness of the tested BMP, its performance relative to other BMPs, and its efficiency under different pollutant loads (refer to Chapter 2). The findings should include a discussion on the following items:

1. Did the pilot study answer its study questions? If yes, how? If not, why not?

2. Describe any qualifications or limits on the conclusions. What were some of the challenges (technical and non-technical) of the pilot study and how were they resolved?

Caltrans evaluates and interprets results of a pilot study using the criteria listed below. Evaluation results of each criterion shall be included in the Final Report.

- **Technical Feasibility:** A recommended BMP must be technically feasible and cannot compromise Caltrans compliance with other laws. Caltrans must be able to implement the BMP within the context of the state highway system. Feasibility also includes health and safety concerns. BMPs that substantially increase the risk to Caltrans employees, contractors, or the public will not be considered feasible.
- **Operation, Maintenance, and Monitoring:** Information from the OM&M activities will be used to evaluate the effectiveness of the BMP.
- **Performance Evaluation:** Empirical and measured results of the pilot study, a comparison of “in” versus “out,” “before” versus “after,” and “with” versus “without,” shall be used to evaluate how well a BMP performed.
- **Costs and Benefits:** The benefits of the BMP must have a reasonable relationship to the costs.

Each one of the criteria is linked to the others. Therefore, it is not realistic to judge a BMP effectiveness or success based solely on data from one or two of the criteria. A basis of selecting one BMP over another shall be developed by assessing all four criteria and evaluating them against the goals and objectives of the study. More guidance on determining the technical feasibility of a BMP are given below.

Technical feasibility information shall be gathered from detailed records kept during the process of designing, building, operating, and maintaining the BMP. Technical feasibility considers siting, design, construction, operation, maintenance, safety, performance, and public health issues. Additional information regarding siting, design, and construction is included in the respective sections of this Manual.

In general, technically feasible BMPs provide the greatest and most consistent reduction of pollutants of interest. Empirical and measured results from the pilot study shall be used to judge the technical feasibility of a BMP and estimate the effectiveness in reducing pollutant mass loadings.

For guidance, the following key criteria are used to measure the technical feasibility, or the acceptability, of a BMP for use at a Caltrans site:

1. The BMP should operate passively during storm events. No personnel are required to be onsite prior to or during a storm even to initiate operation of the BMP or perform routine maintenance to keep the device operational. This does not imply that routine inspections, periodic maintenance, and/or emergency maintenance will not be required to ensure the proper operation of the BMP.

2. Maintenance requirements of a BMP should be well-understood and defined with respect to scope and periodicity. In addition, regular maintenance personnel should be able to perform routine inspections and maintenance tasks using available equipment and without special training. This does not imply that maintenance personnel are not to be trained.

3. Maintenance personnel must be able to perform operational and maintenance inspections and tasks without significant safety risks. Also, safe access to BMPs should be provided.

4. Estimates of the long-term maintenance requirements for the BMP shall be identified.

5. The BMP shall be designed and operated so that it does not create a public nuisance or health hazard (e.g., mosquito vectors).

6. The BMP shall be appropriate for local climatic, geologic, and topographical conditions.

7. Stormwater runoff drainage patterns (i.e., sheet flow or channelized flow) and topography (i.e., gradient and elevation differential) should support the use of a particular BMP type at a specific location.

8. The BMP should be able to be sited within the highway right-of-way clear recovery zone or within a highway-related facility.

9. The BMP should accommodate flow up to and including the design flow rate without flooding.

10. The siting, design, and operation of a BMP shall not produce any significant adverse environmental impacts.

8.11 References

This section is included to acknowledge the originator of borrowed material and to direct the reader to find more information. The list should include all sources used in the course of the study, even if they are not cited within the text. When citing sources within the text, include the source name and the date within parentheses. The source name should be the last name of the author (first author only, if more than one). If the author is an organization, then an appropriate abbreviation should be used. This abbreviation need not be defined in the text. It is merely used as a reference tool. There is no comma between the source name and the year. References should be listed in alphabetical order by in-text citation name.

8.12 Appendices

A number of appendices shall be part of the Final Report. The appendices are intended to capture the raw data, and supporting documents developed during the course of the pilot study. The following is a list of the appendices:

- Study Plan TM
- Study Plan Lessons Learned
- Site Selection TM
- Design Report
- Design Lessons Learned
- Construction Report
- Construction Lessons Learned
- As-Built Plans
- OM&M Plan
- Vector Monitoring and Abatement
- Cost Summary and Analysis
- Data Evaluation
- Post-Storm Technical Memorandum
- Operational Monitoring Reports and Inspection Forms
- Monitoring Data
- Data Validation Results
- Interim Reports
- O&M Lessons Learned
- Electronic Data Submittal
- Caltrans SWIS
- ASCE International Stormwater BMP Database

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Appendix A Requirements for Non-A-E Delivery Methods

The information presented in Chapters 2 through 6 are applicable when all construction activities necessary to execute a pilot study are performed by one or more A-E Consultants. However, under certain circumstances, the Department Task Manager or Contract Manager may choose to perform some or all construction activities by one of the following alternative delivery methods:

- Standard Caltrans Project Delivery Method (“Standard”).
- Contract Change Order (CCO) to an existing roadway contract (“CCO”).

The following sections present specific procedures and guidelines that apply to the various pilot study phases for each delivery method. A brief comparison of the various delivery methods is presented in Section L1.3.

A1.1 Standard Delivery Method

In the first delivery method, sometimes referred to as “design-bid-build,” the preparation of the contract documents (i.e., plans, specifications and estimate) is accomplished by the Project Delivery Team (PDT) (i.e., A-E Consultant), but the construction is performed by a third party contractor who is awarded the contract through normal Department procurement procedures (e.g., public advertisement, public bid opening, and award to the lowest responsible bidder). This method will be referred to as the “Standard” method.

Within this delivery method are sub-categories Minor A, Minor B, and Major projects. The difference between the three is the funding mechanism and the value of construction. Which category is most appropriate for a given project will be determined by the Contract Manager, Department Task Manager, and local NPDES Coordinator.

Pilot Studies utilizing this delivery method (regardless of the sub-category) are required to follow the guidelines presented in the Caltrans Project Development Procedures Manual (PDPM). This manual describes the procedures that all State highway projects must follow to ensure the consistent application of Department policies for project development. As stated in the PDPM (page 1-3):

> *"The project development process is defined as spanning those activities and that time frame that commence with project initiation and end with the assembly of the Final Project Records after project construction."*

The PDPM may be found at www.dot.ca.gov/hq/oppd/pdpm/pdpmn.htm.).

A1.2 Project Planning

In addition to the Study Plan Technical Memorandum (TM), a Project Initiation Document (PID), Preliminary Environmental Assessment Report (PEAR), and Storm Water Data Report (SWDR) may be required at the planning stage of the project.

A1.2.1 Project Initiation Document, WBS 150

The PID is required to obtain management approval of Major projects and to secure the funding for their construction activities. In accordance with the PDPM, no PID is required for Minor A or Minor B projects. The most common form of the PID for a pilot study will be a Project Study Report (PSR). This document identifies the scope, schedule, and estimated cost of potential project alternatives (for a pilot study, the potential alternatives are usually either conducting the pilot study or not conducting it), including the capital outlay components through right of way acquisition (although pilot studies typically don't require additional right of way) and construction, and costs for environmental mitigation and permit compliance. A PSR also must include an inventory of known environmental resources, identification of potential environmental issues and constraints, a description of potential hazardous materials or waste in the project area, the type of environmental document anticipated for NEPA and/or CEQA compliance. SHOPP pilot projects and STIP pilot projects that are statutorily or categorically exempt under CEQA or categorically excluded under NEPA must use the PSR. More information on the PSR and guideline preparations may be found in Chapter 9 and Appendix L of the PDPM, www.dot.ca.gov/hq/oppd/pdpm/pdpmn.htm.

Under certain circumstances, a Project Study Report/Project Report (PSR/PR) may be used as the PID if: the pilot project has a construction value greater than $1,000,000, it is considered noncomplex and non-controversial, it qualifies as a Categorical Exemption, there is only one alternative, and no right-of-way acquisition is necessary. More information on the PSR/PR and guideline preparations may be found in Chapter 9 and Appendix A of the PDPM, www.dot.ca.gov/hq/oppd/pdpm/pdpmn.htm.

In accordance with the implementation of Change Control in July 2000 (www.dot.ca.gov/hq/oppd/design/index.htm), if the pilot project is STIP funded and requires an environmental document (Negative Declaration/Finding of No Significant Impact (ND/FONSI) or Environmental Impact Report/Statements), the Project Study Report (Project Development Support) [PSR(PDS)] must be used to satisfy the PID requirements. This document facilitates programming of STIP projects while meeting the legal requirements of completing a Project Study Report. The PSR(PDS) identifies only the scope, schedule, preliminary cost estimates, and resources necessary to advance the project through Project Approval and Environmental Documentation (PA/ED). Detailed right-of-way and construction cost estimates are deferred until after the project is approved. Guidelines for preparing a PSR(PDS) may be found under Division of Design, Design Memoranda, www.dot.ca.gov/hq/oppd/design/index.htm.

A1.2.2 Preliminary Environmental Analysis Report, WBS 150.20

The environmental review process also commences for Major projects during Project Initiation with the preparation of the PEAR, and is an important part of the PID. Because the environmental process can have a substantial impact on the pilot project design, costs, schedule, and delivery, the review must clearly present and discuss the results of preliminary environmental studies in order to identify environmental constraints that may affect design. The PEAR provides the initial environmental evaluation of a project and all feasible alternatives before it is programmed in the State Transportation Improvement Program (STIP) or State Highway Operation and Protection Program (SHOPP). Those SHOPP projects that qualify for exclusion/exemption do not require the preparation of a PEAR. It is advisable to prepare a PEAR however for all large-scale SHOPP projects that require an environmental document (non-Categorical Exemption) to adequately estimate the schedule and resources to complete the environmental process. It is also recommended that the Interim Scoping Questionnaire for Water Quality Issues is completed for SHOPP projects that do not require a PEAR, to ensure that there are no environmental issues.

The purpose of the PEAR is to determine whether there are any potentially significant environmental issues that could affect the viability of the project alternatives. The PEAR is prepared by Caltrans Environmental Planning and identifies the environmental documents and supporting technical studies that would be required in subsequent project development processes to address potential environmental impacts. The PEAR also estimates the scope, schedule, and costs associated with completing environmental compliance. Based upon the potential for adverse impacts, the review determines whether a CEQA Initial Study or Environmental Impact Report is needed and/or whether a NEPA Environmental Assessment or Environmental Impact Statement is needed. The PEAR Handbook, found at www.dot.ca.gov/ser/pear.htm, may be consulted for additional information.

The Water Quality Impact Questionnaire is also completed during the PEAR process. The questionnaire is meant to identify potential water quality issues early in the project development process. The questionnaire would identify the existing receiving water bodies and their beneficial uses, existing surface water quality, any impairments and unique environmental conditions, and a generalized assessment of potential project-related stormwater quality impacts. This questionnaire evaluates the need for a full Water Quality Assessment Technical Report (WQR).

Preparation of a PEAR is not required for Minor A and Minor B projects. However, the PEAR Checklist, found in Exhibit 2 of the PEAR Handbook, is required for all monitoring pilot studies. The checklist is completed by the PDT and submitted to the Department Task Manager. It will then be routed to the district through the HQ District Environmental Coordinator for the respective district. The purpose is to ensure that all environmental due diligence has been performed and Districts are informed through appropriate channels.

A1.2.3 Storm Water Data Report, WBS 150.25

A planning phase version of the SWDR 5.5 is also required for all Major projects. As specified in Section 5.5, pilot studies may use the SWDR Short Form, but it should be reflected in the Description section that the project is a stormwater pilot study. The PDT prepares the SWDR and includes the signed cover sheet as an attachment to the PID.

No PID-phase SWDR is required for Minor A and Minor B projects.

A1.3 Project Site Selection

The guidelines presented in Chapter 3 apply, and no additional documentation is required.

A1.4 Permits and Environmental Clearance

In addition to the Environmental Document and any applicable permits, a Project Approval Document, Water Quality Assessment, and Storm Water Data Report may also be required at this stage of the project.

A1.4.1 Project Approval Document, WBS 180.05

Department policy requires the preparation of a project approval document for all projects constructed by the Caltrans Standard Delivery Method. The purpose of the document is obtain management approval of a selected preferred alternative, to clearly identify right of way acquisition needs (although this is rarely needed for pilot studies since adequate right of way is usually a screening criteria during site selection), and refine construction costs. The Project Report may not be finalized and approved until the ED is approved. More information on environmental requirements are presented in Section 4.2.

The appropriate project approval document for Major and Minor A projects is a Project Report (PR), and it is the most common project approval document and provides Caltrans' approval of the pilot project. The PR presents the preferred alternative from the potential alternatives previously presented in the PID (for pilot studies, the potential alternatives are typically either conducting the pilot study or not conducting it, and the preferred alternative is conducting the pilot study), and updates the information presented in the PID, if one was prepared. If a PSR/PR was prepared as the PID, then it also serves as the PR and no separate PR is required. More information on the PR and guideline preparations may be found in Chapter 12 and Appendix K of the PDPM, www.dot.ca.gov/hq/oppd/pdpm/pdpmn.htm.

For Minor B projects, the Expenditure Authorization Project Report (EA-PR) serves as the project approval document. The EA-PR is prepared using the one-page Expenditure Authorization Form FA47. Since a PEAR is not required for Minor B projects, an environmental statement is included in the form, such as "This project is Categorically Exempt under Class 1 of the State CEQA Guidelines". More information on the EA-PR and guideline preparations may be found in Chapter 9 and Appendix B of the PDPM, www.dot.ca.gov/hq/oppd/pdpm/pdpmn.htm.

A1.4.2 Storm Water Data Report, WBS 180.05

For Major Projects, the SWDR prepared during Project Planning is revised, updating the appropriate sections with more recent information. For Minor A and Minor B projects, the SWDR will be prepared for the first time since one was not required at the Project Planning phase. The signed cover sheet of the SWDR is included as an attachment to the PR.

A1.4.3 Water Quality Assessment, WBS

The Water Quality Assessment Technical Report (WQR) is a technical report that may be prepared by either the PDT or the Environmental Branch in compliance with CEQA, NEPA, and other key environmental regulations affecting or relating to water quality. The WQR focuses on the physical and chemical water quality impacts of a project, but also provides water quality information to support required regulatory consultation and/or obtaining permits under the California Fish and Game Code (e.g., Sections 1601-1603), federal Clean Water Act (e.g., Section 404, Section 401), California and federal Endangered Species Acts, and the Fish and Wildlife Coordination Act. The WQR identifies and assesses the physical and chemical water quality impacts of projects and identifies categories of Best Management Practices (BMPs) that may be applicable in avoiding or minimizing the impact.

Additional information on WQRs may be found in the SER Volume 1, Chapter 9, at www.dot.ca.gov/ser/vol1/sec3/physical/ch9waterqual/chap9.htm.

A1.5 Project Design

Although the guidelines and tasks presented in Chapter 5 generally apply, the level of detail and review process is more rigorous when the Standard Delivery Method is utilized. This is because the preparation of Major and Minor A construction contract documents for public award is governed by Section 10120 of the Public Contract Code (part of the State Contract Act), which states:

> *"Before entering into any contract for a project, the Department shall prepare full, complete, and accurate plans and specifications and estimates of cost, giving such directions as will enable any competent mechanic or other builder to carry them out."*

The Caltrans RTL ensures compliance with the above-mentioned code by providing procedures and instructions for contract document preparation. Additional information on the RTL Guide may be found on the Office Engineer website, at www.dot.ca.gov/hq/esc/oe/specifications/rtl_guide/.

Minor B projects are not formally subject to the provisions of the RTL Guide. However, unless otherwise directed by the Department Task Manager or Contract Manager, it is recommended that Minor B pilot project designs follow RTL Guide provisions to ensure consistency between all pilot projects performed by Caltrans.

A1.5.1 PS&E Production, WBS 230

The Typical Roadway Plan Set presented in Table 5.1 still applies, but the submittal/review process is different when the Standard Delivery Method is used. PS&Es prepared in accordance with the RTL Guide are reviewed and approved by District functional units, the District Office of the Office Engineer, and the Headquarters Office of the Office Engineer. Furthermore, the District Office Engineer typically does not review the package until it has been approved by the functional units, and the Headquarters Office Engineer will not review it until it has been approved by the District Office Engineer.

A1.5.1.1 Plans

Given the review process described above, it is not uncommon for Major and Minor a projects to go through the following submittal process:

- Draft Submittal (e.g., 30% complete), reviewed by HQ Stormwater
- Draft Submittal (e.g., 60% complete), reviewed by District Functional Units
- Revised Submittal (e.g., 90% complete), reviewed by District Office Engineer
- Revised Submittal (e.g., 95% complete), reviewed by District Office Engineer
- Pre-Final Submittal (e.g., 95% complete), reviewed by HQ Office Engineer
- Final Submittal (e.g., 100% complete), approved by HQ Office Engineer

Minor B projects are not reviewed by the District Office of the Office Engineer or the Headquarters Office of the Office Engineer. The Department Task Manager should be consulted to determine which plans from the list in Table 5.1 are required for the first draft submittal, but it typically consists of complete or partially complete versions of the Title Sheet, Layouts, Contour Grading, Drainage Plans, and Drainage Profiles. The first draft submittal to the district typically includes all the plans from the list except for the various Quantity Sheets. The first revised submittal, and all subsequent submittals should be a complete plan set.

A1.5.1.2 Specifications

For Standard Delivery Method projects, the specifications must be separate from the drawings, and the drawings must not contain any specifications. In addition, Caltrans has strict procedures regarding the use of non-SSPs, including the need for an individual (referred to as the “owner”) to sponsor the non-SSP (the request for an owner is initiated by the District OE), and review/approval it. The owner may someone within the appropriate district functional unit or the Department Task Manager. As a result, non-SSPs requirements should be identified as early in the design process as possible to ensure that the review and approval process do not cause delays in the schedule.

A1.5.1.3 Estimate

The guidelines presented in Section 5.3.3 apply.

A1.5.2 Design Timelines

Typical durations for a PS&E process following the Standard Delivery Method are presented in Table L.1, while a graphical timeline is presented in Figure L-1. Timelines represented in diagonal patterns are PDT-performed tasks, and timelines represented in vertical/horizontal patterns are tasks performed by Caltrans departments who are not part of the PDT (such as District Functional Units and Office Engineer). The horizontal and backward-diagonal pattern bars represent the minimum duration, (Early Start/Finish) while the vertical and forward-diagonal bars represent the maximum duration (Late Start/Finish).

Table A.1 Typical Pilot Study PS&E Timeline (Caltrans Standard Delivery Method)

Activity	WBS	Duration (weeks)
Field Investigations	185.xx	4 - 8
Preparation and submittal of Draft (30%) PS&E	215.xx	4 – 12
Review of Draft (30%) PS&E by HQ Stormwater	215.xx	3 – 6
Preparation and submittal of Draft (60%) PS&E	230.xx	4 – 14
Review of Draft (60%) PS&E by District Functional Units	255.05	3 – 6
Preparation and submittal of Revised (90%) PS&E	255.10	4 – 12
Review of Revised (90%) PS&E by District Office Engineer	255.20	3 – 6
Preparation and submittal of Revised (95%) PS&E	255.10	2 – 6
Review of Revised (95%) PS&E by District Office Engineer	255.20	2 – 6
Preparation and submittal of Pre-Final (95%) PS&E	255.10	2 – 4
Review of Pre-Final (95%) PS&E by HQ Office Engineer	255.20	4 – 6
Preparation & submittal of Final (100%) PS&E	255.20	2 – 4
Review/approval of Final (100%) PS&E by HQ Office Engineer	255.20	2 – 4
Total		**39 – 94**

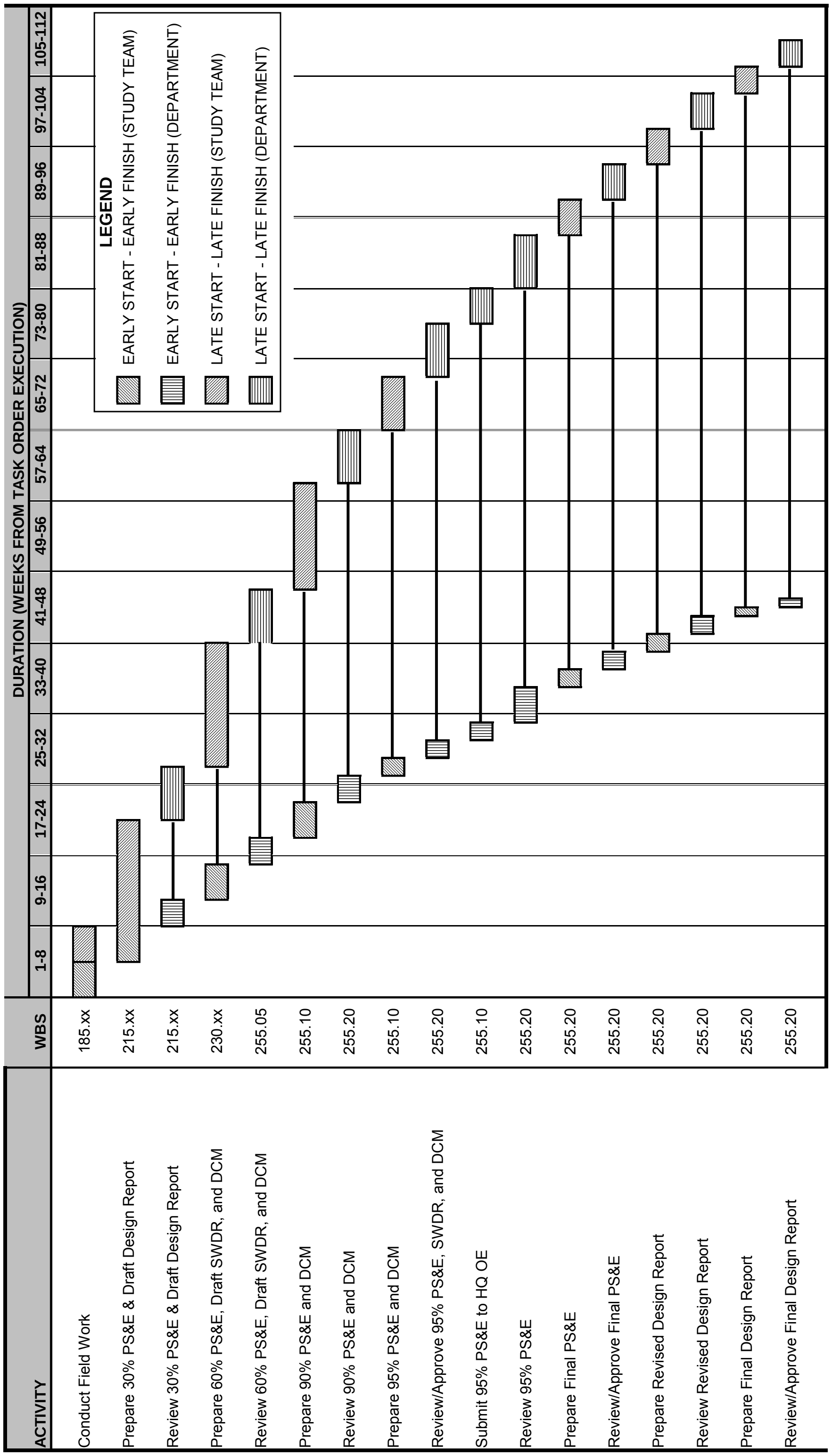

Figure A-1 Typical Pilot Study PS&E Timeline (Standard Delivery Method)

A1.5.3 Task Order Development

The guidelines presented in Section 5.7 apply.

A1.6 Project Construction

The following subsections present the revisions to the information presented in Chapter 6 when the Caltrans Standard Delivery Method is utilized.

A1.6.1 Construction and Installation

Construction is the responsibility of Caltrans and is performed by a third party under contract with Caltrans. Caltrans will provide a construction project manager, Resident Engineer (RE) and inspector(s). PDT participation includes part-time independent oversight (required by HQ Stormwater) and as-needed services requested by the Resident Engineer. These as-needed services include the following:

- Participation in Kickoff Meeting with RE.
- Participation in Pre-construction Meeting with RE and Contractor.
- Review of Contractor Submittals, RFIs, and RFCs.
- Assistance with preparation of Contract Change Orders.
- Conducting a Pre-Final Inspection.
- Assistance with Certificate of Environmental Compliance.

The above services are considered optional because participation of the PDT is at the discretion of the Construction Project Manager and/or Resident Engineer. If the PDT is requested to attend either the kickoff or pre-construction meeting, meeting minutes should be prepared (by the PDT) and submitted to the Caltrans Task Manager. If the PDT is requested to perform a pre-final inspection prior to Caltrans accepting the project, a Punch List (a list of all items that the Contractor must correct or complete before the job is considered finished) shall be prepared and submitted to the Resident Engineer and Caltrans Task Manager. In addition to the Punch List, the Department has an environmental close-out process during Construction Contract Acceptance (CCA) requiring certification (CEC). This certification documents that environmental compliance and commitments have been executed as prescribed by the Department’s final environmental (or other project) documentation, including permits and agreements. See Volume 1, Chapter 39 of the SER for additional information, at http://www.dot.ca.gov/ser/index.htm.

A1.6.2 Water Pollution Control

Water Pollution Control is the responsibility of Caltrans.

A1.6.3 Hazardous Waste Management

Hazardous Waste Management is the responsibility of Caltrans.

A1.6.4 Submittals, RFIs, and RFCs

During construction under the Caltrans Standard Delivery Method, it is not uncommon for the Contractor to have questions regarding the interpretation of the drawings and specifications, or to encounter a situation in which the drawings and/or specifications need to be revised. Given that the PS&E was prepared by the PDT, they are usually retained (if, for example, the A-E Consultant is contractually available) to provide engineering services during construction. The services are on an as-needed basis, are requested at the discretion of the Resident Engineer, and usually include review of Contractor submittals (i.e., shop drawings), responding to Contractor Requests for Information (RFI), responding to Contractor Requests for Clarification (RFC), and preparation of Contract Change Order (CCO) documents. There are no standard formats for RFIs and RFCs as Caltrans accepts contractor-generated documents. Preparation of CCOs must follow the format presented in the Caltrans Construction Manual (www.dot.ca.gov/hq/construc/manual2001/).

A1.6.5 Progress Documentation

At a minimum, the role of the PDT is to provide part-time (weekly) field inspection services to document the progress of the work and independently check the work against the contract documents (plans and specifications). Given that the inspections are only conducted weekly, the individual conducting the visit must focus his/her efforts on key pilot facility elements that are critical to the pilot study (such as monitoring components, treatment components, and permanent erosion control) and rely on Caltrans resources for the more typical roadway project items of work (such as traffic control, earthwork, water pollution control, and roadway work). As presented in Chapter 5, the Design Report provides a list of the key elements to be independently checked by the PDT during construction. A Construction Site Visit Report shall be prepared after each visit and submitted to the Resident Engineer, Construction Project Manager, and Caltrans Task Manager. The report includes the following information:

- Construction EA Number and Site ID/Name
- Date and time of the site visit
- Period of report
- Names of Resident Engineer, Construction Project Manager, and Caltrans Task Manager
- Weather conditions
- Contractor personnel on site

- Equipment on site
- Summary of general progress made since last site visit
- Summary/status of key construction features
- Concerns and/or issues
- Photographs, with date imprints
- Name and signature (electronic) of individual performing site visit

The entries in the "Construction Issues/Concerns Discussed" section should be assigned a numerical number to facilitate tracking, and a running log should be maintained and submitted to the Department Task Manager during the construction phase. The entries in the "Key Construction Items" section must be approved by the Department Task Manager. In addition, a log should be maintained of Key Construction Items that are not installed per the contract documents, and provided to the Department Task Manager along with the report. The report should be submitted within three working days of the visit. An example Construction Site Visit Report is presented in Figure L-2.

District 12 Route 73 Pilot Study
Weekly Construction Site Visit Report

Period Covered: 10/12/05 - 10/18/05 **Report Date:** 10/19/05, 1:00 pm

Contract:	12-0C9854
BMP Site:	780R
Project Mgr:	Diba Kazerani
Resident Eng:	Kifah Ramadan
Dept. Task Mgr:	Tim Sobelman

Day	S	M	T	**W**	Th	F	S
Weather	Bright	Sunny	**Over Cast**	Rain	Snow		
Temp.°F	<32	32-50	50-70	**70-85**	85-100		
Wind	**Still**	Moderate	High				
Humidity	Dry	**Moderate**	Humid				

Average Field Force			
Name of Contractor	**Admin**	**Field**	**Remarks**
PPC	1	7	

Equipment on Site

- 1 – Komatsu PC228USLC Track Hoe
- 1 – Cat 936F Loader
- 1 – Cat 420D Backhoe/Loader
- 1 – Kubota KH-60 Track Hoe
- 1 – Electronic Sign Board
- 1 – Bobcat 90E Loader
- 1 – Dynapac 4469 6ft Sheepsfoot Roller
- 1 – 2000 Gallon Water Truck
- 1 – Case 60XT Loader
- 2 – Wacker Trench Roller
- 1 – Wacker Vibratory Rammer

Construction Activities

- Limited production during report period due to rain
- Removed CSF and backfilled area
- Initiated trenching for pipe installation to concrete channel
- Placed and compacted base at inflow monitoring location
- Installed forms for inflow monitoring station floor
- Poured the floor and installed rebar for walls at outflow monitoring location
- Placed the 1200mm APC from outflow monitoring station
- Continued trenching for pipe installation
- Continued grading at flood control basin
- Continued "step" excavation for basin liner at north and east side

Key Construction Items				
Item	Installed yet?		Installed per contract docs?	
Outlet Riser	☐ Yes	☒ No	☐ Yes	☐ No
Monitoring	☐ Yes	☒ No	☐ Yes	☐ No
Skimmer	☐ Yes	☒ No	☐ Yes	☐ No

Page 1 of 2

Figure A-2 Example Construction Site Visit Report

District 12 Route 73 Pilot Study
Weekly Construction Site Visit Report

Period Covered: 10/12/05 - 10/18/05 **Report Date:** 10/19/05, 1:00 pm

Construction Issues/Concerns Discussed
4. Met with Inspector. Concerns discussed were: 1) unexpected dewatering required for trenching to the concrete channel 2) unexpected dewatering required for excavating for the inflow monitoring station floor

Progress Photographs


Project Area (looking south)


Concrete Channel Trench


Basin Liner


Outflow Monitoring Station Floor

Report Prepared By: ______________________

Page 2 of 2

Figure A-2 (cont.) Example Construction Site Visit Report

A1.6.6 Post Construction

Following completion of construction, the PDT is responsible for preparation of the Construction Report and possibly the As-Builts. If the Resident Engineer chooses to have the PDT prepare the As-Builts, he/she will provide the PDT with the redline markups maintained by the Contractor and the RE. The As-Builts should reflect only the changes identified on the marked-up plans and no others.

A1.6.7 Typical Construction Timeline

A typical timeline for the construction process following the Standard Delivery Method is presented in Figure L-3. The format and representations of the timelines are the same as that described previously. Depending on the complexity of the project, the construction phase may take anywhere from 36 to 85 weeks.

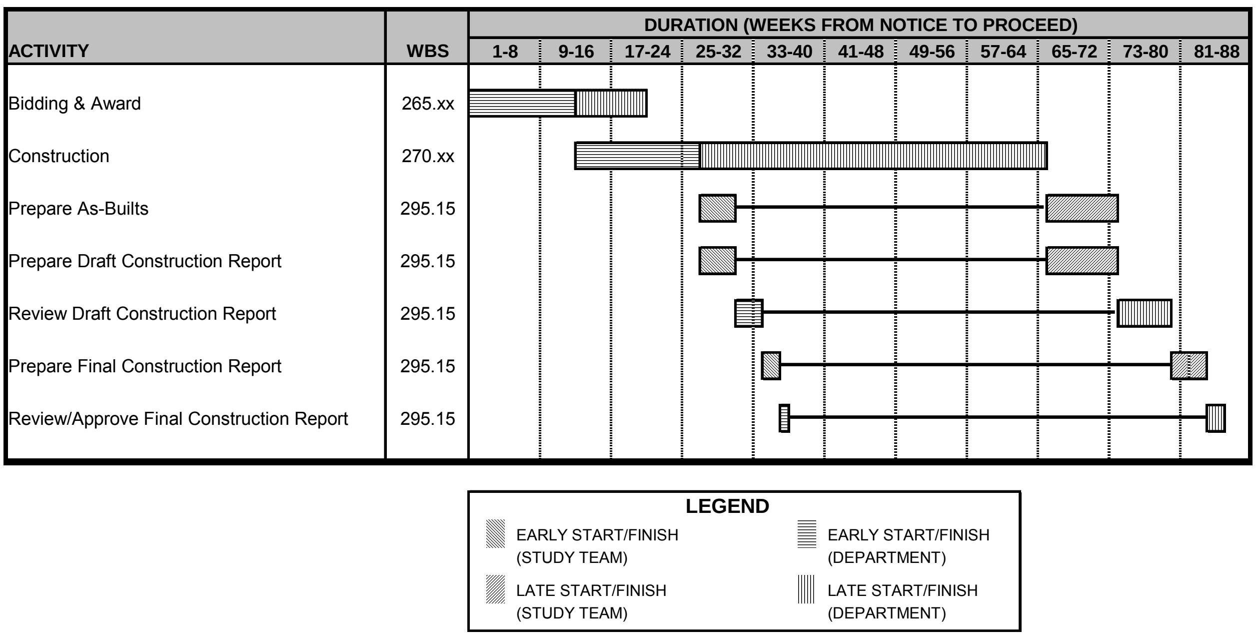

Figure A-3 Typical Pilot Study Construction Timeline (Standard Delivery Method)

A1.6.8 Task Order Development

Unless directed otherwise by the Department Task Manager, task orders for construction activities should include, at a minimum, the following scope elements:

Scope Element	WBS	Brief Description	Deliverable(s)
Project Management	100.xx	Administration, Coordination, Scheduling, and Quality Control	Meeting Minutes Monthly Progress Reports Invoices
Construction Administration	270.25	Administration of Construction/Installation tasks	Pre-Construction Meeting Minutes
Construction Inspection	270.30	Oversight and inspection of construction activities to ensure compliance with contract documents	Construction Site Visit Reports Concerns and Issues Log
Contract Acceptance	295	Acceptance of construction activities and preparation of final documents	Pre-final inspection Punch List As-Builts Construction Report

A1.7 CCO Delivery Method

The second delivery method is similar to the previous method in that the contract documents are prepared by the PDT and the construction is performed by a third party contractor. The primary difference however, is that instead of publicly advertising the project and awarding the contract to the low bidder, Caltrans adds the pilot study construction activities to an existing ongoing contract as a Contract Change Order (CCO). This method is typically employed when other construction is already ongoing in the area, the pilot project work fits within the existing project's Area of Potential Effect, no environmental re-evaluation is necessary, no additional right-of-way is necessary, and an accelerated pilot study schedule is desired.

Examples from the Files ....

The District 11 Biofiltration Swale BMP Pilot at I-5 & Palomar Airport Road was constructed by the CCO Delivery Method. This was because there was an ongoing roadway construction contract at the project location, the proposed change adhered to the existing permit conditions and environmental requirements, and the roadway contractor had already mobilized.

A1.8 Project Planning

The guidelines presented in Chapter 2 apply, and no additional documentation is required.

A1.9 Project Site Selection

The guidelines presented in Chapter 3 apply, and no additional documentation is required.

A1.10 Permits and Environmental Clearance

The guidelines presented in Chapter 4 apply, and no additional documentation is required.

A1.11 Project Design

Similar to Minor B projects, CCO contract documents are not formally subject to the provisions of the RTL Guide However, unless otherwise directed by the Department Task Manager or Contract Manager, it is recommended that Minor B pilot project designs follow RTL Guide provisions to ensure consistency between all pilot projects performed by Caltrans.

A1.11.1 PS&E Production, WBS 230

The Typical Roadway Plan Set presented in Table 5.1 still applies (except for the Title Sheet which is not necessary since one already exists for the existing contract), but the submittal/review process is different. CCO designs are not reviewed by the District Office of the Office Engineer or the Headquarters Office of the Office Engineer. They are subject to a limited review, as determined by the Caltrans Task Manager, Department Project Manager (PM) and the Caltrans Resident Engineer (RE) responsible for the existing contract.

A1.11.1.1 Plans

A typical submittal/review process for CCO pilot study designs is as follows:

- Draft Submittal (e.g., 30% complete), reviewed by HQ Stormwater
- Draft Submittal (e.g., 60% complete), reviewed by RE
- Revised Submittal (e.g., 90% complete), reviewed by RE
- Final Submittal (e.g., 100% complete), approved by RE

The Department Task Manager and RE should be consulted to determine which plans from the list in Table 5.1 are required for the first draft submittal, but it typically consists of complete or partially complete versions of the Layouts, Contour Grading, Drainage Plans, and Drainage Profiles. The first draft submittal to the RE typically includes all the plans from the list except for the various Quantity Sheets. The revised submittal, and all subsequent submittals should be a complete plan set.

A1.11.1.2 Specifications

The specifications may either follow the guidelines presented in Chapter 5 or Section L-1, whichever the RE determines to be more appropriate.

A1.11.1.3 Estimate

The guidelines presented in Section 5.3.3 apply.

A1.11.2 Design Timelines

Typical durations for a PS&E process following the CCO Delivery Method are presented in Table L.2, while a graphical timeline is presented in Figure L-4. The format and representations of the timelines are the same as that described previously. Depending on the complexity of the project, the design phase may take anywhere from 20 to 66 weeks.

Table A.2 Typical Pilot Study PS&E Timeline (CCO Delivery Method)

Activity	WBS	Duration (weeks)
Field Investigations	185.xx	2 – 6
Preparation and submittal of Draft (30%) PS&E	215.xx	3 – 12
Review of Draft (30%) PS&E by HQ Stormwater	215.xx	3 – 6
Preparation and submittal of Draft (60%) PS&E	230.xx	3 – 12
Review of Draft (60%) PS&E by RE	255.05	3 – 6
Preparation and submittal of Revised (90%) PS&E	255.10	2 – 12
Review of Revised (90%) PS&E by RE	255.20	2 – 4
Preparation & submittal of Final (100%) PS&E	255.20	1 – 4
Review/approval of Final (100%) PS&E by RE	255.20	1 – 4
Total		**20 – 66**

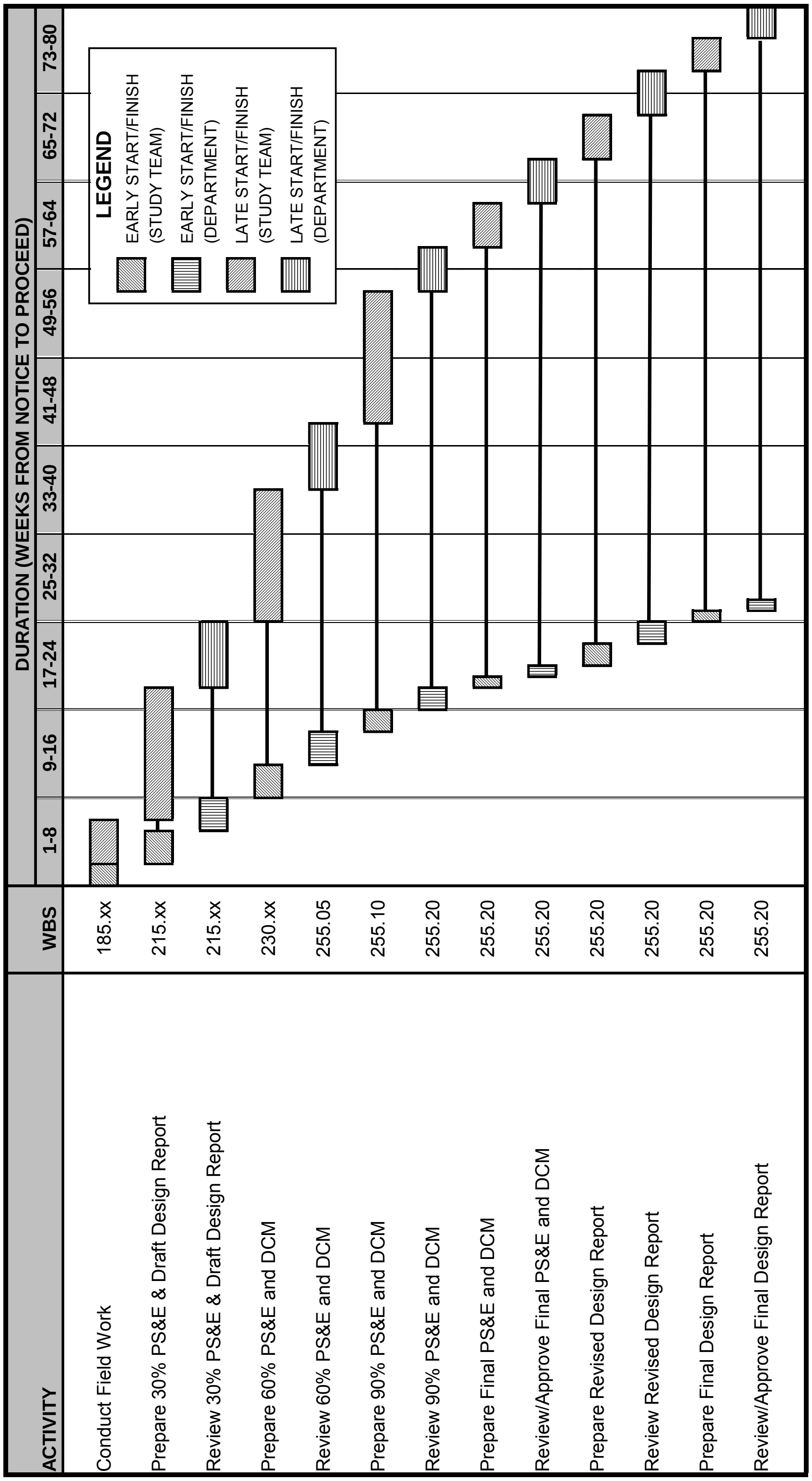

Figure A-4 Typical Pilot Study PS&E Timeline (CCO Delivery Method)

A1.12 Project Construction

The following subsections present the revisions to the information presented in Chapter 6 when the Caltrans Standard Delivery Method is utilized.

A1.12.1 Construction and Installation

The same guidelines presented in Section L.1.5.1 apply.

A1.12.2 Water Pollution Control

Water Pollution Control is the responsibility of Caltrans.

A1.12.3 Hazardous Waste Management

Hazardous Waste Management is the responsibility of Caltrans.

A1.12.4 Submittals, RFIs, and RFCs

The same guidelines presented in Section L.1.5.4 apply.

A1.12.5 Progress Documentation

The same guidelines presented in Section L.1.5.5 apply.

A1.12.6 Post Construction

The same guidelines presented in Section L.1.5.6 apply.

A1.12.7 Typical Construction Timeline

A typical timeline for the construction process following the CCO Delivery Method is presented in Figure L-5. The format and representations of the timelines are the same as that described previously. Depending on the complexity of the project, the construction phase may take anywhere from 21 to 58 weeks.

A1.12.8 Task Order Development

The same guidelines presented in Section L.1.5.8 apply.

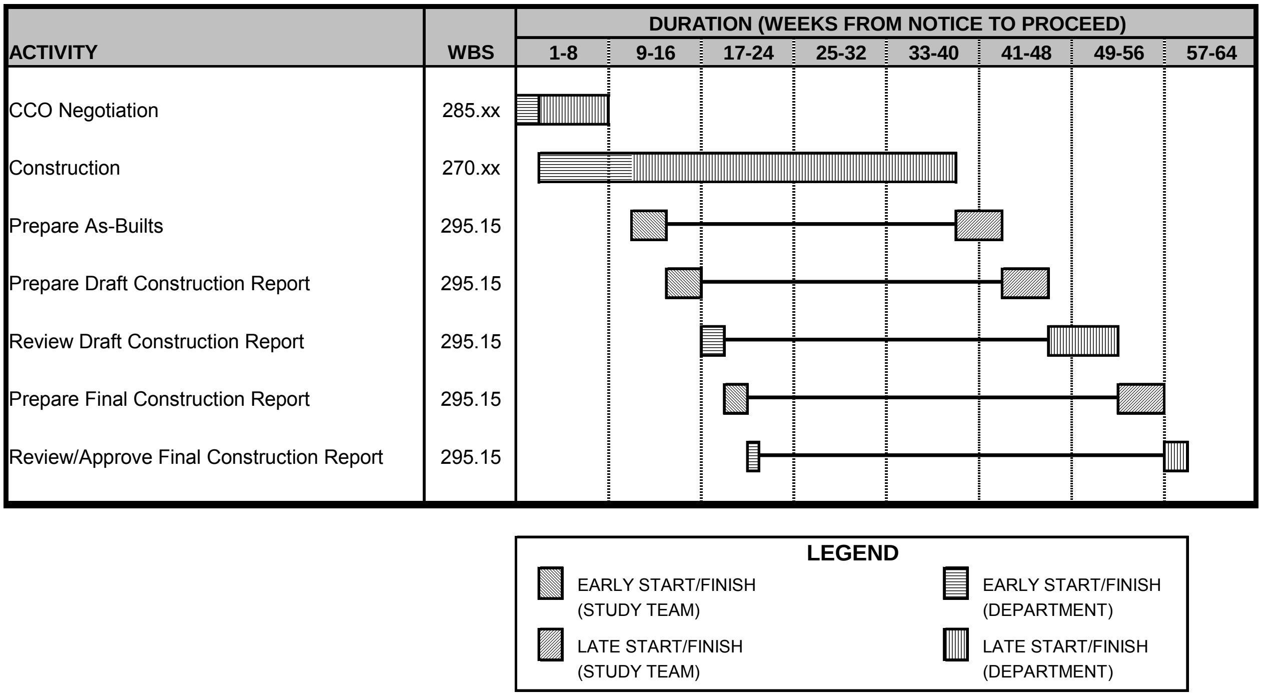

Figure A-5 Typical Pilot Study Construction Timeline (CCO Delivery Method)

A1.13 Delivery Method Comparison

Four delivery methods have been presented in this manual: construction is performed by the same A-E Consultant who performed the design [identified as a-E(1)]; construction is performed by an A-E Consultant other than the one who performed the design [identified as A-E(2)]; construction is performed by a third party contractor selected by the Department using standard project procurement procedures [identified as Std]; and construction is performed by a third party contractor already under contract to the Department for an unrelated project in the same area as the BMP [identified as CCO]. A brief summary of the requirements of each delivery method is presented in Table L.3, and a comparison of the relative advantages and disadvantages of each are presented in Table L.4.

Table A.3 Delivery Method Summary

	A-E(1)	A-E(2)	Std	CCO
Project Planning	Study Plan TM required. SWDR may be required.	Same as A-E(1)	Study Plan TM, PID, and SWDR required. PEAR may be required	Same as A-E(1)
Site Selection	Site Selection TM required	Same as A-E(1)	Same as A-E(1)	Same as A-E(1)
Permits & Environmental Clearance	Environmental Document required. Permits, Water Quality Assessment, and SWDR may be required	Same as A-E(1)	Project Approval Document, Environmental Document, and SWDR required. Permits and Water Quality Assessment may be required	Typically, nothing required as long as BMP is within existing contract project limits
Design	Dept. Task Mgr defines PS&E needs, and may need to comply with RTL Guide, Plan Preparation Manual, and CADD Users Manual. PS&E not reviewed by OE.	Same as A-E(1)	PS&E must comply with RTL Guide, Plan Preparation Manual, and CADD Users Manual. PS&E reviewed and approved by OE.	RE defines PS&E needs, and may need to comply with RTL Guide, Plan Preparation Manual, and CADD Users Manual. PS&E not reviewed by OE.
Construction	A-E Design Consultant responsible for all aspects of construction	A-E Consultant other than Design Consultant responsible for construction. A-E Design Consultant provides support to Dept. Task Mgr as needed.	Construction by third party, PDT provides support to RE and performs weekly site visits	Same as Std

Table A.4 Delivery Method Comparison

	A-E(1)	A-E(2)	Std	CCO
Advantages	Shortest project duration (planning, design, and construction) and possibly lowest design costs.	Shorter duration than Std method while maintaining a separation between design and construction	Full compliance with PDPM, RTL Guide, and Caltrans Construction Manual. Open bid process with award to lowest responsive bidder.	May be as short as A-E(1) in duration or shorter, depending on RE needs for PS&E and CCO negotiation. Full compliance with Caltrans Construction Manual.
Disadvantages	Construction cost may not be as low as Std method since A-E Consultant might use own forces and may not solicit bids.	Construction cost may be higher than Std since A-E Consultant might use own forces and may not solicit bids, and may be higher than A-E(1) due to A-E Design Consultant involvement. Construction duration may be longer than A-E(1) due to transition period and plans.	Longest duration for Planning (due to PID), Environmental Clearance (due to Project Approval Document), Design (due to OE approval), and Construction (due to advertisement, award, and contract execution)	Construction cost may not be as low as Std method since cost is negotiated with Contractor. Construction duration may be longer due to CCO negotiation process.

Appendix B Study Plan Technical Memorandum

B1.1 Introduction

A three or four sentence introduction is needed to set the stage for pilot study planning. Include a brief description, purpose, cost, and fiscal year (i.e., provide the intent of the project [the "big picture"] and define why the pilot study is necessary).

B1.2 Describe the Problem

1. Provide a concise discussion of the problem.
2. Confirm if a pilot study is necessary and specify how the pilot study will help the Department solve the problem or fill the need.

B1.3 Define the Study Goals

1. Provide background information; literature review may be required.
2. Describe the BMP and its unit processes.
3. State principal study questions.
4. Discuss key assumptions that have the potential to influence the study outcome.

B1.4 Specify Study Type

1. Specify the study type, i.e., the monitoring approach (Influent-Effluent Comparison, Upstream-Downstream, Before-After, or Paired Watersheds Approach).

B1.5 Identify Study Variables

1. Discuss types and sources of data expected to be collected in the study to answer the study questions.
2. Specify variables that may affect the data based on consideration of site characteristics, BMP characteristics, storm characteristics, and maintenance practices.
3. Check assumptions to assure important variables are not being ignored.

B1.6 Specify Study Methodology and Analytical Approach

1. Specify how the study variables will be treated (i.e., specify which study variables are to be fixed, which ones will be constrained or controlled, and which ones will be monitored).
2. Define site selection parameters that apply to the pilot study site(s).

3. Specify BMP physical characteristics and operational procedures.
4. Determine the length of the study period and the number of BMPs to be monitored to achieve the desired level of statistical confidence.
5. Specify the data collection methods.
6. Specify the statistical analysis techniques to be used to analyze the data.

B1.7 Data Quality Objectives

1. Discuss the data validation procedure that will be used to evaluate the usability of the data. Techniques include using the Caltrans Hydrology Utility, EDD Checker, and Automated Data Validation Software.
2. Specify acceptable limits on measurement uncertainty.

B1.8 Schedule and Cost

1. Provide a general timeline for the pilot study and develop cost estimates.

B1.9 Summary

1. Summarize information generated in previous steps.
2. State project constraints.
3. Document and justify a design that will yield data that will best meet study goals.
4. List trade-offs due to optimization.

B1.10 Reporting Requirements

Using the list below, check off the report(s) that are applicable to the recommended pilot study:

- Site Selection Technical Memorandum
- Design Report
- Design Lessons Learned
- Construction Report
- Construction Lessons Learned
- As-Built Plans
- OM&M Plan
- Vector Monitoring and Abatement
- Cost Summary and Analysis
- Data Evaluation
- Post-Storm Technical Memorandum

- Operational Monitoring Reports and Inspection Forms
- Monitoring Data
- Data Validation Results
- O&M Lessons Learned
- Electronic Data Submittal
- Caltrans SWIS
- ASCE International Stormwater BMP Database
- Other

B1.11 References

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Appendix C Site Selection Technical Memorandum

C1.1 Executive Summary

- Project Description
- Candidate Sites
- Screening Criteria Matrix
- Siting Criteria Scoring Matrix
- Results

C1.2 Introduction

- Project Description
- Project Background
- Candidate Sites

C1.3 Siting Criteria Development

- Siting Criteria Selection
    - Pilot Design Requirements/BMP Design Requirements
    - Monitoring Requirements
    - Safety Requirements
    - Implementation Issues
- Screening Criteria
- Evaluation Criteria
- Weighting Factors

C1.4 Data Collection and Analysis

- Data Collection, Analysis, and Review of Existing Data
    - Caltrans Documents Reviewed
    - Other Documents Reviewed
- Preliminary Sizing Approach

C1.5 Siting Deviations that Impact Study Plan

- Study Plan Deviations
- Impacts to Pilot Study Objectives

C1.6 Site Evaluations and Analysis

- Assumptions
- Screening Criteria Matrix
- Siting Criteria Valuation Matrix
- Siting Criteria Normalization Matrix
- Siting Criteria Scoring Matrix

C1.7 Summary of Results and Recommendations

C1.8 References

C1.9 Appendices

- Field Investigation Forms (including photos)

Appendix D Design Report

D1.1 Introduction

- Project Description
- Project Background
- Project Location
- Units
- Report Organization

D1.2 Existing Site Conditions

- Data Sources
- Topography
- Geotechnical Investigations
- Climate and Hydrology
- Soils
- Groundwater
- Stormwater Conveyance and Treatment
- Utilities
- Hazardous Wastes
- Environmental Setting
- Other Hazards

D1.3 Design Criteria

- BMP Design and Monitoring Criteria
  - Water Quality Volume
  - Water Quality Flow
  - Monitoring
  - Maintenance
  - Safety
  - Flood Control
  - Structural Design
  - Electrical / Power
  - Vegetation General Design Criteria

  - Existing Facilities
  - Utilities
  - Hazardous Wastes
  - Landscaping and Irrigation
  - Environmental

D1.4 Hydrologic and Hydraulic Analysis

- Methodology
  - Design Criteria
  - Model Description and Inputs
- Watershed Delineation Rainfall Analysis
  - IDF Parameters
  - Rainfall Depths
  - Design Storms
- Existing Condition Modeling Results
  - Inflow
  - Outflow
- Project Condition Modeling Results
  - Outflow Hydrographs
  - Outflow Hydraulics

D1.5 Design Deviations that Impact Study Plan

D1.6 Design Summary

- BMP Design
  - Inlet Structures
  - Outlet Structures
  - Treatment System
  - Monitoring
  - Maintenance
  - Safety
  - Flood Control
  - Structural Design

  - Electrical / Power
  - Existing Facilities
  - Utilities
  - Vegetation (for treatment)
  - Landscaping and Irrigation
  - Hazardous Wastes
  - Environmental

- Non-Standard Special Provisions
- Design Costs
- Construction Cost Estimate
- Lessons Learned

D1.7 Construction Support

- Shop Drawings Requiring Consultant Review
- Items of Work Requiring Special Attention
- Key Measurements / Observations to be Made

D1.8 OM&M Support

- Monitoring Approach and Features
- Operations & Maintenance Approach and Features

D1.9 References

D1.10 Appendices

- Existing Plans
- Watershed Delineation Maps
- Intensity-Duration-Frequency Curves
- Hydrology & Hydraulic Calculations
- Design Calculations
- CD Containing Final PS&E

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Appendix E Construction Report

E1.1 Introduction

- Project Description
- Project Location
- Report Organization

E1.2 Bid Phase Summary

- Bid Addenda
- Bid Summary

E1.3 Construction Phase Summary

- Shop Drawing Review
- Requests for Information / Clarification
- Contract Change Orders
  - Plans
  - Special Provisions
  - Schedule
- Acceptance Testing
- Final Construction Cost
- Lessons Learned

E1.4 Construction Deviations that Impact Study Plan

E1.5 OM&M Support

- Changes that impact monitoring
- Changes that impact operations & maintenance

E1.6 References

E1.7 Appendices

- RFI / RFC Log
- CCO Log
- Daily Construction Reports
- Weekly Construction Site Visit Reports
- Final Cost Breakdown
- CD Containing As-Built Plans
- Example Environmental Commitment Record
- Certificate of Environmental Compliance

Appendix F Operation, Maintenance, and Monitoring Plan

F1.1 Introduction

- Study Description
- Study Objectives
- BMP Description
- General Scope of Activities (Maintenance and Monitoring)
- Project Organization and Responsibilities

F1.2 Description of Site

- Site Access
- Health and Safety Plan (reference in appendix)
- BMP Features

F1.3 Operation and Maintenance

- Routine Inspection and Maintenance Requirements
- Equipment and Tools Needed
- Checklist for Inspectors and Maintenance Personnel

F1.4 Operation and Maintenance Costs

- Inspection and Maintenance Cost Tracking Database

F1.5 Monitoring

- Data Quality Objectives
- Analytical Constituents
- Monitoring Equipment
- Monitoring Preparation and Logistics
    - Weather Tracking
    - Storm Selection Criteria
    - Storm Action Levels
    - Communication/Notification Procedures
    - Monitoring and Equipment Preparation

- Sample Collection, Preservation, and delivery
- Quality Assurance/Quality Control
- Laboratory Sample Preparation and Analytical Methods
- Data Management and Reporting Procedures

F1.6 Appendices

- Site Maps and Plans
- Equipment Data Sheets
- Field Forms
- Vector Control and Management Procedures
- Health and Safety Plan

Appendix G Final Report

The Final Report shall be a comprehensive documentation of the Study Plan, implementation, and findings. The report shall be organized based on the following outline.

G1.1 Report Cover

Reports shall include the following information on the document cover:

- Caltrans logo
- Title of report
- Report date
- Report number
- California Department of Transportation
- Division of Environmental Analysis
  Storm Water Program
  1120 N Street, Sacramento, California
- http://www.dot.ca.gov/hq/env/stormwater/index.htm
- Sensory disabilities statement

G1.2 Executive Summary

The Executive Summary shall provide the reader a concise overview of the pilot study, from inception through implementation, to conclusions and recommendations.

G1.3 Introduction

G1.3.1 Purpose

1. Identify the problem that requires new data. (Section 2 of the Study Plan TM).
2. Describe the purpose of the study. (Section 1 of the Study Plan TM).

G1.3.2 Project Overview and Objectives

Summarize the principal study questions. (Section 3 of the Study Plan TM).

G1.3.3 BMP Description

Describe the BMP technology. (Section 1 of the OM&M Plan).

G1.3.4 Study Plan

1. Discuss the development of the DQOs. (Section 7 of the Study Plan TM).
2. Describe how the data was selected to be collected. (Section 4 of the Study Plan TM).
3. Describe the key parameters to monitor. (Section 5 of the Study Plan TM).
4. Describe the statistical methods that were initially identified to be appropriate for the type of data collected. (Section 6 of the Study Plan TM).

G1.3.5 Report Organization

Describe the contents and organization of the report.

G1.4 Study Plan, Site Characteristics, and Key Design Features

G1.4.1 Site Selection

1. Discuss the site selection criteria.
2. Describe the selected sites.
3. Describe how well the selected sites met the selection criteria.
4. Reference the Site Selection TM in appendix.

G1.4.2 Site Characteristics

Describe the site-specific characteristics. Refer to the EPA/ASCE document entitled Task 1.1 – National Stormwater BMP Data Elements (www.bmpdatabase.org/docs/dataelement.pdf) for BMP features that shall be summarized.

G1.4.3 Project Permits, Design and Construction

1. Note any important permit.
2. Briefly describe the design methodology. Refer to Basis of Design and Final Design Reports in the appendix.
3. Present important design features. Refer to as-built plans in appendix.
4. Describe any design issues
5. Describe any construction issues.

G1.5 Monitoring Methodology

G1.5.1 Monitoring Program

1. Describe the type of events monitored and why.
2. Describe the criteria used to decide if an event was to be monitored.
3. Describe the criteria used to start and stop monitoring.

G1.5.2 Flow and Precipitation Measurement

1. Describe the monitoring or other sources of information used for stormwater flow and precipitation measurement.
2. Provide a discussion of calibration of field equipment, including methods, results, and changes made based on the calibrations.

G1.5.3 Sampling Methods

1. Describe stormwater sampling methods.
2. Provide a discussion of calibration of field equipment, including methods, results, and changes made based on the calibrations.

G1.5.4 Analytical Methods

Summarize the analytical methods that were used.

G1.5.5 Operational Monitoring Methods

Summarize the methods used to inspect and maintain the BMP. In particular, include the maintenance indicator thresholds.

G1.6 Monitoring Results

G1.6.1 Quality Assurance/Quality Control

Discuss the quality assurance/quality control (QA/QC) results. In particular, discuss sample representativeness and data validation results.

G1.6.2 Monitored Events

Describe the events that were monitored throughout the study.

G1.6.3 Rainfall and Flow Monitoring Results

1. Summarize in tabular form the rainfall and flow monitoring results.
2. Include the hydrographs/hyetographs in an appendix.

G1.6.4 Operational Monitoring Results

1. Include an assessment of maintenance requirements.
2. Describe any proposed changes/enhancements to the maintenance indicator thresholds.

G1.6.5 Analytical Results

Summarize in tabular form the analytical results.

G1.7 BMP Performance

G1.7.1 Methods for Analysis of Data

Discuss statistical methods and justification for using them.

G1.7.2 Summary Statistics

Summarize the statistical results in narrative, tabular, and graphical form, as appropriate.

G1.7.3 Objectives and Findings

Provide a section for each study objective, and discuss the analysis of the data relative to that objective.

G1.7.4 Performance Evaluation

Provide narrative evaluation of performance, including discussion of data quality on which performance is assessed.

G1.8 Maintenance Requirements

1. Include discussion of the adequacy of the MID.
2. Describe any proposed changes/enhancements to the maintenance indicator thresholds.

G1.9 Capital, Operations, and Maintenance Costs

1. Summarize capital, operation, and maintenance costs.
2. Discuss the difference in maintenance needs and associated costs that may be caused by climate and geography (detailed back-up data shall be provided in an appendix).
3. Provide whole-life cost analysis, using the WERF model or equivalent (refer to input data and interactive spreadsheet for the WERF in an appendix).

G1.10 Conclusions

1. Was the study successful in collecting sufficient data of good quality to meet the study objectives?
2. Note statistical considerations in drawing conclusions from limited data.
3. Discuss data quality issues.
4. What conclusions can be drawn relative to each study objective?

G1.11 Recommendations

G1.11.1 Suggested Improvements to Technology

Describe any improvements to the tested BMP technology that are recommended as a result of the pilot study.

G1.11.2 Suggested Changes to Maintenance Procedures

Describe recommendations for maintenance frequency, thresholds, and activities.

G1.11.3 Suggested Design Criteria

Describe recommendations for design criteria.

G1.11.4 Recommendations for Additional Studies

1. Should further monitoring be continued at these sites?
2. If yes, why and for how long?
3. If no, why not, and what is the next step?

G1.12 References

This section is included to acknowledge the originator of borrowed material and to direct the reader to find more information. The list should include all sources used in the course of the study, even if they are not cited within the text.

G1.13 Appendices

- Study Plan TM
- Study Plan Lessons Learned
- Site Selection TM
- Design Report
- Design Lessons Learned
- Construction Report
- Construction Lessons Learned
- As-Built Plans
- OM&M Plan
- Vector Monitoring and Abatement
- Cost Summary and Analysis
- Data Evaluation
- Post-Storm Technical Memorandum

- Operational Monitoring Reports and Inspection Forms
- Monitoring Data
- Data Validation Results
- Interim Reports
- O&M Lessons Learned
- Electronic Data Submittal
- Caltrans Master Stormwater Database
- ASCE International Stormwater BMP Database

Appendix H References

American Society of Civil Engineers. 2002. Urban Stormwater BMP Performance Monitoring. EPA/821/B-02/001. U.S. Environmental Protection Agency, Office of Water.

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National Pollutant Discharge Elimination System (NPDES) General permit for Storm Water Discharges Associated with Construction Activity (General Permit). Water Quality Order 99-08-DWQ.

SWRCB Order No. 99-06-DWQ, NPDES Permit No. CAS000003, Statewide Stormwater Permit and WDRs for Caltrans (General Permit). 1999.

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Appendix I Abbreviations, Acronyms & Definitions of Terms

ABBREVIATIONS

ac	acre
cfs	cubic feet per second
cy	cubic yards
ft	feet
hr	hour
in	inch
in/hr	inch per hour
km	kilometer
M	meter
M^2	square meters
M^3	cubic meters
mm	millimeter
Std	standard

ACRONYMS

ACOE	U.S. Army Corps of Engineers
ADL	Aerially Deposited Lead
ASCE	American Society of Civil Engineers
BAT	Best Available Technology
BCDC	Bay Conservation and Development Commission
BMP	Best Management Practice
BODR	Basis of Design Report
Caltrans	California Department of Transportation
CCA	Construction Contract Acceptance
CCC	California Coastal Commission
CCO	Contract Change Order
CE	Categorical Exemption or Categorical Exclusion
CEC	Certificate of Environmental Compliance
CEQA	California Environmental Quality Act
DFG	California Department of Fish and Game
DQO	Data Quality Objective
DTSC	California Department of Toxic Substances Control
EA	Environmental Assessment
ECR	Environmental Commitments Record
ED	Environmental Document
EIR	Environmental Impact Report

ACRONYMS (Continued)

EIS	Environmental Impact Statement
ELAP	Environmental Laboratory Accreditation Program
EP	Encroachment Permit
FDR	Final Design Report
FHWA	Federal Highway Administration
IS	Initial Study
ISA	Initial Site Assessment
MEP	Maximum Extent Practicable
NEPA	National Environmental Policy Act
ND	Negative Declaration
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
O&M	Operations and Maintenance
OM&M	Operations, Maintenance and Monitoring
PCR	Post-Construction Report
PDPM	Project Development Procedures Manual
PDS	Project Development Support
PDT	Project Delivery Team
PEAR	Preliminary Environmental Analysis Report
PID	Project Initiation Document
PM	Department Project Manager
PR	Project Report
PS&E	Plans, Specifications and Estimate
PSR	Project Study Report
RCRA	Resource Conservation and Recovery Act
RTL	Ready-To-List and Construction Contract Award Guide
SER	Standard Environmental Reference
SEZ	Stream Environment Zone
SHOPP	State Highway Operation and Protection Program
SSP	Standard Special Provisions
STIP	State Transportation Improvement Program
SWDR	Stormwater Data Report
SWMP	Stormwater Management Plan
SWPPP	Stormwater Pollution Prevention Plan
SWRCB	State Water Resources Control Board
TM	Technical Memorandum
TRPA	Tahoe Regional Planning Agency
VCD	Vector Control District
WDR	Waste Discharge Requirements
WERF	Water Environment Research Foundation
WPCP	Water Pollution Control Program
WQA	Water Quality Assessment
WQF	Water Quality Flow
WQV	Water Quality Volume

DEFINITION OF TERMS

Antecedent Moisture: Amount of moisture present in soil prior to the application of a soil stabilization product.

Best Management Practice (BMP): Any program, technology, process, siting criteria, operating method, measure, or device that controls, prevents, removes, or reduces pollution.

Construction Activity: Includes clearing, grading, or excavation and contractor activities that result in soil disturbance.

Construction Site: The area involved in a construction project as a whole.

Contamination: An impairment of the quality of the waters of the state by waste to a degree that creates a hazard to the public health through poisoning or through the spread of disease including any equivalent effect resulting from the disposal of waste, whether or not waters of the state are affected.

Contractor: Party responsible for carrying out the contract per plans and specifications. The Standard Specifications and Special Provisions contain stormwater protection requirements the contractor must address.

Desert Areas: Areas within the Colorado River Basin RWQCB and the North and South Lahontan RWQCB jurisdictions (excluding the Mono and Antelope areas, East and West Walker River, East and West Carson River, and the Truckee and Little Truckee River).

Discharge: Any release, spill, leak, pump, flow, escape, dumping, or disposal of any liquid, semi-solid or solid substance.

Environmental Protection Agency (EPA): Agency that issued the regulations to control pollutants in stormwater runoff discharges (The Clean Water Act and NPDES permit requirements).

Erosion: The wearing away of land surface primarily by wind or water. Erosion occurs naturally as a result of weather or runoff but can be intensified by clearing, grading, or excavation of the land surface.

Erosion Control Effectiveness: The ability of a particular product to reduce soil erosion relative to the amount of erosion measured for bare soil. Percentage of erosion that would be reduced as compared to an untreated or control condition.

Fair Weather Prediction: When there is no precipitation in the forecast between the current calendar day and the next working day. The National Weather Service NOAA Weather Radio forecast shall be used. The contractor may propose an alternative forecast for use if approved by the Resident Engineer.

Feasible: Economically achievable or cost-effective measures, which reflect a reasonable degree of pollutant reduction achievable through the application of available nonpoint pollution control practices, technologies, processes, site criteria, operating methods, or other alternatives.

General Permit: The General Permit for Stormwater Discharges Associated with Construction Activity (Order No. 99-08-DWQ, NPDES Permit CAS000002) issued by the State Water Resources Control Board.

National Pollutant Discharge Elimination System (NPDES) Permit: A permit issued pursuant to the Clean Water Act that requires the discharge of pollutants to waters of the United States from stormwater be controlled.

Non-Stormwater Discharge: Any discharge to a storm drain system or receiving water that is not composed entirely of stormwater.

Permit: The Caltrans Statewide NPDES Permit (see Statewide Permit), General Construction Permit, or local permit, whichever is applicable to the construction project.

Programming: The process by which a public agency or a private company identifies specific funds for a project, based on a projection of revenues expected to be available at a specific time in the future.

Pollution: The man-made or man-induced alteration of the chemical, physical, biological, and radiological integrity of water. An alteration of the quality of the water of the state by waste to a degree, which unreasonably affects either the waters for beneficial uses or facilities that serve these beneficial uses.

Rainy Season: The dates of the rainy season shall be as specified: use dates in the local permit if a local permit is applicable to the project site and rainy season dates are specified therein; or, if the local permit does not specify rainy season dates and/or in areas of the state not subject to a local permit, the rainy season dates shall be determined from the General Permit.

Receiving Waters: All surface water bodies within the permit area.

Regional Water Quality Control Board (RWQCB): California agencies that implement and enforce Clean Water Act Section 402(p) NPDES permit requirements, and are issuers and administrators of these permits as delegated by EPA. There are nine regional boards working with the State Water Resources Control Board.

Resident Engineer (RE): The Caltrans representative charged with administration of construction contracts. The RE decides questions regarding acceptability of material furnished and work performed. The RE has “contractual authority” to direct the contractor and impose sanctions if the contractor fails to take prompt and appropriate action to correct deficiencies. The following contractual sanctions can be imposed by the RE: (a) withholding payments (or portions of payments), (b) suspending work, (c) bringing in a separate contractor to complete work items (the contractor is billed for such costs), (d) assessing liquidated damages including passing along fines for permit violations, and/or (e) initiating cancellation of the construction contract.

Sediment: Organic or inorganic material that is carried by or suspended in water and that settles out to form deposits in the storm drain system or receiving waters.

Statewide Permit: The National Pollutant Discharge Elimination System (NPDES) Permit, Statewide Stormwater Permit and Waster Discharge Requirements (WDRs) for the State of California Department of Transportation (Caltrans). Order No. 99-06-DWQ, NPDES No. CAS000003.

State Water Resources Control Board (SWRCB): California agency that implements and enforces Clean Water Act Section 402(p) NPDES permit requirements, is issuer and administrator of these permits as delegated by EPA. Works with the nine Regional Water Quality Control Boards.

Stormwater: Rainfall runoff, snow melt runoff, and surface runoff and drainage. It excludes infiltration and runoff from agricultural land.

Stormwater Pollution Prevention Plan (SWPPP): A plan required by the Permit that includes site map(s), an identification of construction/contractor activities that could cause pollutants in the stormwater, and a description of measures or practices to control these pollutants. It must be prepared and approved before construction begins. A SWPPP prepared in accordance with the special provisions and the Handbooks will satisfy Standard Specifications Section 7-1.01G - Water Pollution, requirement for preparation of a program to control water pollution.

Water Pollution Control Program (WPCP): A program that must be prepared and implemented by the construction contractor under Standard Specifications Section 7-1.01G - Water Pollution.

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Appendix J Project Initiation Document (PID)

This appendix describes the Project Initiation phase (i.e., project development pre-programming phase). More information on the Project Initiation phase may be found in Chapter 9 of the PDPM, www.dot.ca.gov/hq/oppd/pdpm/pdpmn.htm.

J1.1 Project Initiation Document, PID WBS 150

As presented in the Project Development Procedures Manual, the project planning phase (also known as Project Initiation), is a pre-programming phase of project development for the Caltrans Standard Delivery Method and is used to obtain management approval of candidate State Transportation Improvement Program (STIP), Toll Bridge, Traffic Systems Management (TSM) Plan or State Highway Operation and Protection Program (SHOPP) Major projects, or concept approval of projects 100 percent funded by others. The outcome of the Project Initiation process is a well-defined, proposed project scope tied to a reliable cost estimate and schedule, and an initial environmental evaluation suitable for programming or local commitment and for proceeding to the environmental documentation and project alternative selection phase.

If the Caltrans Standard Delivery Method is being used, and it is a Major project, Department and CTC policy requires the preparation of a Project Initiation Document (PID) prior to their programming in any programming document (including the STIP, the SHOPP, the TSM and the Toll Bridge Program). The most common form of the PID for a pilot study is a Project Study Report (PSR). More information on the PSR and guideline preparations may be found in Chapter 9 and Appendix L of the PDPM, www.dot.ca.gov/hq/oppd/pdpm/pdpmn.htm.

Under certain circumstances, a Project Study Report/Project Report (PSR/PR) may be used as the PID if: the pilot project has a construction value greater than $1,000,000, it is considered noncomplex and non-controversial, it qualifies as a Categorical Exemption, there is only one alternative, and no right-of-way acquisition is necessary. More information on the PSR/PR and guideline preparations may be found in Chapter 9 and Appendix A of the PDPM, www.dot.ca.gov/hq/oppd/pdpm/pdpmn.htm.

In accordance with the implementation of Change Control in July 2000 (www.dot.ca.gov/hq/oppd/design/index.htm), if the pilot project is STIP funded and requires an environmental document (Initial Study/Environmental Assessment [IS/EA] or Environmental Impact Report/Environmental Impact Statement [EIR/EIS]), the Project Study Report (Project Development Support) [PSR(PDS)] must be used to satisfy the PID requirements. This document facilitates programming of STIP projects while meeting the legal requirements of completing a Project Study Report. The PSR(PDS) identifies only the scope, schedule, preliminary cost estimates, and resources necessary to advance the project through Project Approval and Environmental Documentation (PA/ED). Detailed right-of-way and construction cost estimates are deferred until after the project is approved. Guidelines for preparing a PSR(PDS) may be found under Division of Design, Design Memoranda, www.dot.ca.gov/hq/oppd/design/index.htm.

Coordination with the Caltrans Task Manager and local District NPDES Coordinator is recommended to determine which type of PID is required. No PID is required for Minor A and Minor B projects under the Caltrans Standard Delivery Method, or for any projects under the A-E Contract Delivery Method or CCO Delivery Method.

J1.2 Preliminary Environmental Assessment Report, WBS 150.20

The environmental review process also commences for Major projects during Project Initiation with the preparation of the Preliminary Environmental Analysis Report (PEAR), and is an important part of the PID. Because the environmental process can have a substantial impact on the pilot project design, costs, schedule, and delivery, the review must clearly present and discuss the results of preliminary environmental studies in order to identify environmental constraints that may affect design. The PEAR provides the initial environmental evaluation of a project and all feasible alternatives before it is programmed in the State Transportation Improvement Program (STIP). Although a PEAR is not required for SHOPP projects, environmental screening to identify environmental constraints or permits is recommended. It is advisable to prepare a PEAR, however, for all large-scale SHOPP projects that require an environmental document (non-Categorical Exemption) to adequately estimate the schedule and resources to complete the environmental process.

The purpose of the PEAR is to identify environmental constraints, permit requirements, and determine whether there are any potentially significant environmental issues that could affect the viability of the project alternatives. The PEAR is prepared by Caltrans Environmental Planning and identifies the environmental documents and supporting technical studies that would be required in subsequent project development processes to address potential environmental impacts. The PEAR also estimates the scope, schedule, and costs associated with completing environmental compliance. Based upon the potential for adverse impacts, the review determines whether a CEQA Categorical Exemption, Initial Study, or Environmental Impact Report is needed and/or whether a NEPA Categorical Exclusion, Environmental Assessment, or Environmental Impact Statement is needed. The PEAR Handbook, found at www.dot.ca.gov/ser/pear.htm, may be consulted for additional information.

The Water Quality Impact Questionnaire is also completed during the PEAR process. The questionnaire is meant to identify potential water quality issues early in the project development process. The questionnaire would identify the existing receiving water bodies and their beneficial uses, existing surface water quality, any impairments and unique environmental conditions, and contain a generalized assessment of potential project-related stormwater quality impacts. This questionnaire evaluates the need for a full Water Quality Assessment Technical Report (WQR).

Preparation of a PEAR is not required for Minor A and Minor B projects under the Caltrans Standard Delivery Method, or for any projects under the A-E Contract Delivery Method or CCO Delivery Method. The PEAR Checklist, found in Exhibit 2 of the PEAR Handbook, is required for all monitoring pilot studies. The checklist is completed by the PDT and sent to the Department Task Manager. It will then be routed to the District through the HQ District Environmental Coordinator for the respective District. The purpose is to ensure that all environmental due diligence has been performed and Districts are informed through appropriate channels.

J1.3 Storm Water Data Report, WBS 150.25.25

Another requirement during Project Initiation for Major projects under the Caltrans Standard Delivery Method is the preparation of the Stormwater Data Report (SWDR), which summarizes the stormwater quality issues of the pilot project. The SWDR is a Caltrans documentation process for stormwater decisions at each project development phase. There are two types of SWDRs, depending on the extent of soil disturbance and degree of stormwater impacts. Pilot projects that do not have the potential to create stormwater impacts and have little or no soil disturbance (less than 1 acre) may use the "Short Form" SWDR. Pilot projects that do not qualify for the Short Form must use the "Long Form" SWDR. Detailed guidelines and instructions for preparing SWDRs may be found in the Stormwater Quality Handbook –PPDG and the Division of Design, Stormwater Management website, both of which are found at www.dot.ca.gov/hq/oppd/stormwtr/index.htm.

The PDT prepares the SWDR and includes the signed cover sheet as an attachment to the PID. No SWDR is required for Minor A and Minor B projects under the Caltrans Standard Delivery Method, or for any projects under the A-E Contract Delivery Method or CCO Delivery Method.

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Appendix K Statistical Appendices

Table K provides a cross-reference to the title of each appendix and the topics covered in it. The intended audience for these appendices is engineers and scientists who have little or limited background in statistics. Accordingly, the focus is not on the theory of the statistical methods, but rather on the selection of an appropriate statistical method, interpretation of results, understanding of the limitations of the analysis method, and drawing of valid conclusions. Flowcharts of step-by-step procedures are provided to guide the user to appropriate decisions or actions. References are provided regarding the theoretical basis of the various methods.

It is assumed that the user will have access to statistical analysis software packages and therefore will not need to use any equations to calculate results. The software package will be used instead to perform all calculations and generate typical output reports. As a result, few equations are included in the appendices. References are provided which include detailed equations for the various methods.

Emphasis is placed on graphical and numerical data summaries that facilitate the understanding of salient features of the input and output. Illustrative examples related to BMP studies are provided to show the organization of input data and output reports for a typical software package. Important portions of the reports are annotated and explained.

The specific commercial statistical software package used to analyze the illustrative examples in this manual is JMP developed by the SAS Institute (www.jmp.com). Other software packages, including Minitab (www.minitab.com), SAS (www.sas.com), SPSS (www.spss.com), and SysStat (www.systat.com), are also available. Any of these packages will be adequate for the types of statistical analysis that may be used in typical BMP studies. Although the specific procedures and commands vary for the different packages, typical parts of the output reports are similar. The annotated output reports from JMP, included in the appendices, should be useful in understanding similar reports from other software packages.

Table K Topics Covered in Each Statistical Appendix

Appendix	Title	Typical Study Questions Addressed
K1	How to Estimate an Adequate Number of Samples	How many samples would I need to achieve desired confidence in the conclusions? After one or two years of sampling, how do I decide whether I would need more samples than initially planned?
K2	How to Examine Data Quality and Detect Possible Outliers in the Data	How do I prepare graphical and numerical data summaries to understand salient data features and identify potential outliers?
K3	How to Examine Data Quality in the Presence of Non-detect Values	How do I account for non-detect results?
K4	How to Verify Common Assumptions for the Selection of an Appropriate Statistical Test	How do I verify whether data are normally distributed? How do I verify that the data variability of two or more groups is similar?
K5	How to Estimate Probabilities Using Data for a Single Variable	How do I estimate how often the average BMP effluent concentration would meet a legal limit? How do I estimate the BMP percentage removal of a pollutant with a specified confidence level?
K6	How to Compare Two Independent Data Sets	In an upstream-downstream watershed approach or paired watersheds approach, how do I decide whether a given BMP is effective in removing a pollutant? How do I compare the effectiveness of two pilot BMPs at a given geographic location?
K7	How to Compare Two Paired Data Sets	In an influent-effluent approach or before-after approach, how do I decide whether a given BMP is effective in removing a pollutant?
K8	How to Compare Three or More Independent Data Sets	How do I compare the effectiveness of three or more pilot BMPs at a given geographic location?
K9	How to Develop a Linear Regression Equation	How does BMP effectiveness vary as a function of such other factors as storm characteristics, BMP design variables, and operation/maintenance practices?
K10	How to Evaluate Time Trends in BMP Monitoring Data	How can I tell if the effectiveness of my pilot BMP is changing over time?

Appendix K1 How to Estimate an Adequate Number of Samples

K1.1 Purpose and Organization

The purpose of this appendix is to present statistical methods to estimate an adequate number of samples ("sample size") needed to answer various questions of interest in BMP pilot studies. If the sample size is too small, the variability in a particular data parameter (such as the mean pollutant concentration) could be large, and this variability may mask the true effectiveness of a particular BMP. The smaller the sample size, the greater the risk of failing to detect a true BMP difference, all other things being equal. The basic principle in developing a statistics-based sampling plan is that the sample size should be large enough so that the risk of failing to detect some minimum specified difference is sufficiently small.

This appendix describes statistical procedures that could be used to estimate an adequate number of samples in the planning stage of BMP studies. This appendix also describes statistical procedures that could be used for an interim data review. Such a review would be conducted after data have been collected for one year to check the adequacy of the original estimate of the sample size and decide whether additional data would be needed to meet the study objectives. Examples are included to illustrate the use of the statistical procedures in typical BMP pilot studies.

K1.2 Statistical Procedures for Estimating Sample Size in the Planning Stage

Statistical procedures for estimating the sample size depend on the specific questions being addressed in the BMP study. For purposes of estimating sample sizes, the study questions can be grouped based on the number of independent data sets being analyzed – one, two, or more – for a given measure of water quality or BMP effectiveness. In his book, Gilbert[5] defined independent data sets as those for which there is no natural way to pair the data. For BMP studies, pairing could occur because of spatial or temporal association between data points. For example, in an influent-effluent approach, pollutant concentrations may be measured in the water entering into and exiting from a BMP at several BMP locations. In this case, the influent and effluent concentrations would be paired by the BMP location. Concentration differences or percent

[5] Gilbert, Richard O.1987. *Statistical Methods for Environmental Pollution Monitoring.* Van Nostrand Reinhold, New York.

removals can be calculated to define a single data set. In a before-after approach, concentrations may be measured at several locations before and after implementing a particular BMP maintenance action. In this case, concentration differences or percent removals would define a single data set and the data again would be paired by the sampling location. On the other hand, data collected in a paired watershed approach would result in two independent data sets. In this approach, data may be collected at multiple locations in each of two watersheds – control (undisturbed) and treatment (disturbed). There is no natural pairing between a particular sampling location in one watershed and a sampling location in the other watershed. Table K1.1 shows typical study questions in each group. The following sections describe the statistical procedures that could be used to estimate the sample size for each group.

Table K1.1 Typical Study Questions for Comparison of Independent Data Sets

Number of Independent Data Sets	Typical Study Questions
1	For pollutant concentrations measured with an influent-effluent, upstream-downstream, or before-after monitoring approach, does a BMP remove a pollutant by more than a specified percentage? Does the effluent pollutant concentration exceed a specified legal limit?
2	For pollutant concentrations measured with a paired watershed monitoring approach, does a BMP remove a pollutant by more than a specified percentage? Is the performance of two BMPs in a similar environment setting significantly different? Is the performance of a given BMP significantly different in two different environmental settings?
3 or more	Given influent and effluent data for three pilot BMPs of the same type, how can one tell whether they are all operating in an equivalent manner, or whether there is some site-specific factor that causes one BMP to operate differently than the others? Is the performance of a given BMP significantly different in three different environmental settings?

K1.3 Study Questions Involving a Single Data Set

A single data set could be an independent data set in its own right, or it could be the combined result of two related data sets to form a paired data set. For example, the effluent concentration of a given chemical constituent downstream of a treatment or source control BMP would be a single independent data set. An example of a paired data set would be influent and effluent concentrations of a given pollutant upstream and downstream of a BMP. This is a paired data set because the effluent quality depends on the influent quality. A logical way to combine the two sets of data in a paired data set is to calculate the percentage removal of a pollutant or difference in concentrations, which results in a single data set.

The statistical procedure for estimating the sample size for this case focuses on the minimum change, Δ, in the mean value of the parameter of interest. For example, in the case where the percent pollutant removal is of interest, one could specify Δ of 20 percent. This would mean that the sample size should be large enough to detect a pollutant removal of 20 percent or more with high confidence. Another study question for this group is whether the average concentration of a pollutant constituent exceeds a specified limit (e.g., a legal water quality standard). For this study question, Δ will be the minimum absolute or percentage increase in the average concentration above the standard that should be detected with high confidence.

The procedure to estimate the sample size for this case also depends on the distribution that could be assumed for the data set. Three different cases of data distribution could be considered – normal distribution, lognormal distribution, or neither.

K1.3.1 A Single Data Set with Normal Distribution

The sample size, *n*, depends on the following factors:

- Standard deviation of the data, *s*. Since no data would have been yet collected at the planning stage, the standard deviation is typically estimated based on prior data at similar sites or professional judgment. Tables K1.2 and K1.3 contain means and standard deviations from past Caltrans field studies. Influent statistics are tabulated in Table K1.2. BMP percent removal statistics are tabulated in Tabkle K.1.3 and are based on the category of BMP of interest.
- In the interim data review stage (i.e., after collecting data for one or two years), the initial estimate of the standard deviation can be checked and revised if necessary.
- The minimum change in the average value of the parameter of interest (e.g., average removal of a specified pollutant), Δ. This factor may be based on applicable legal or regulatory

Table K1.2 Descriptive Statistics for Selected Constituents, Influent[1]

	Constituent	Unit	Highway Facilities			Maintenance Facilities		
			Mean	Std Dev	n	Mean	Std Dev	n
Conventionals	TOC	mg/L	21.8	29.2	635	20.6	23.0	107
	DOC	mg/L	18.7	26.2	635	18.2	18.2	75
	EC	µS/cm	96.1	73.4	634	80.9	110.6	56
	Hardness as $CaCO_3$	mg/L	36.5	34.2	635	26.7	28.7	106
	Chloride	mg/L	266	388	32			
	TDS	mg/L	87.3	103.7	635	68.9	78.1	106
	TSS	mg/L	112.7	188.8	634	96.4	95.0	106
	Turbidity	NTU				144.8	92.23	29
Hydro-carbons	Oil & Grease	mg/L	4.95	11.41	49			
	TPH (Diesel)	mg/L	3.72	3.31	32			
	TPH (Gasoline)	mg/L						
	TPH (Heavy Oil)	mg/L	2.71	3.4	20			
Metals	As, dissolved	µg/L	1.0	1.4	635	9.5	17.3	106
	As, total	µg/L	2.7	7.9	635	12.8	23.1	107
	Cd, dissolved	µg/L	0.24	0.54	635	0.27	0.22	106
	Cd, total	µg/L	0.73	1.61	635	0.69	0.63	107
	Cr, dissolved	µg/L	3.3	3.3	635	1.4	1.0	106
	Cr, total	µg/L	8.6	9.0	635	5.1	4.3	107
	Cu, dissolved	µg/L	14.9	14.4	635	14.3	17.6	106
	Cu, total	µg/L	33.5	31.6	635	29.5	37.6	107
	Hg, dissolved	µg/L				27.7	51.4	7
	Hg, total	µg/L	36.7	37.9	23	65.4	83.7	8
	Ni,dissolved	µg/L	4.9	5.0	635	3.7	4.0	106
	Ni, total	µg/L	11.2	13.2	635	7.9	7.7	107
	Pb, dissolved	µg/L	7.6	34.3	635	1.6	3.0	106
	Pb, total	µg/L	47.8	151.3	635	21.3	26.5	107
	Zn, dissolved	µg/L	68.8	96.6	635	21.3	26.5	107
	Zn, total	µg/L	187.1	199.8	635	245.6	259.3	107
Micro-bio-logical	Fecal Coliform	MPN per	1132	1621	32			
	Total Coliform	100 mL	13438	34299	32			
Nutrients	NH_3-N	mg/L	1.08	1.46	8			
	NO_3-N	mg/L	1.07	2.44	634	0.74	1.13	107
	Ortho-P, dissolved	mg/L	0.11	0.18	630	0.09	0.40	105
	P, total	mg/L	0.29	0.39	631	0.23	0.20	106
	TKN	mg/L	2.06	1.90	626	1.79	1.72	105
Pesticides Herbicides	Chlorpyrifos	µg/L						
	Diazinon	µg/L	0.13	0.29	34	0.12	0.30	23
	Diuron	µg/L	4.60	18.24	367			
	Glyphosate	µg/L	19.61	26.97	541			

Table K1.2 Descriptive Statistics for Selected Constituents, Influent2 (cont'd)

	Constituent	Unit	Park and Ride Facilities			Construction Sites		
			Mean	Std Dev	n	Mean	Std Dev	n
Conventionals	TOC	mg/L	18.6	20.6	179	12.8	9.9	47
	DOC	mg/L	18.0	28.6	179	11.1	8.4	47
	EC	µS/cm	63.5	65.8	179	370.7[1]	1659.8[3]	88
	Hardness as $CaCO_3$	mg/L	36.6	45.9	179	185.2	885.7	118
	Chloride	mg/L						
	TDS	mg/L	61.7	78.3	179	327.1	1448.4	117
	TSS	mg/L	68.5	59.3	179	539.3	995.7	118
	Turbidity	NTU			2	685.0	2098.3	19
Hydro-carbons	Oil & Grease	mg/L				0.67	0.90	30
	TPH (Diesel)	mg/L						
	TPH (Gasoline)	mg/L						
	TPH (Heavy Oil)	mg/L						
Metals	As, dissolved	µg/L	0.7	0.6	179	2.1	1.7	47
	As, total	µg/L	1.4	5.9	179	4.5	4.0	47
	Cd, dissolved	µg/L	0.12	0.12	179	IDD	IDD	118
	Cd, total	µg/L	0.30	0.30	179	0.58	1.17	118
	Cr, dissolved	µg/L	1.0	0.9	179	5.7	6.4	118
	Cr, total	µg/L	4.0	4.2	179	38.6	70.5	118
	Cu, dissolved	µg/L	8.7	8.8	179	7.3	5.9	117
	Cu, total	µg/L	17.1	15.2	179	37.2	92.8	118
	Hg, dissolved	µg/L						
	Hg, total	µg/L	57.3	73.6	11			
	Ni,dissolved	µg/L	3.3	3.9	179	3.1	2.6	118
	Ni, total	µg/L	6.2	4.8	179	57.4	283.2	118
	Pb, dissolved	µg/L	1.3	2.7	179	1.1	4.3	118
	Pb, total	µg/L	10.3	11.5	179	56.4	277.6	118
	Zn, dissolved	µg/L	10.3	11.5	179	45.5	433.8	118
	Zn, total	µg/L	154.3	157.1	179	190.3	555.8	118
Micro-bio-logical	Fecal Coliform	MPN per				1777	4268	25
	Total Coliform	100 mL				3915	12023	26
Nutrients	NH_3-N	mg/L				0.29	0.47	116
	NO_3-N	mg/L	0.57	0.83	10	0.96	0.79	71
	Ortho-P, dissolved	mg/L	0.15	0.19	10	0.16	0.24	85
	P, total	mg/L	0.33	0.42	10	1.98	13.47	115
	TKN	mg/L	2.28	2.20	10	2.11	2.53	116
Pesticides Herbicides	Chlorpyrifos	µg/L				0.05	0.12	108
	Diazinon	µg/L				0.24	0.40	108
	Diuron	µg/L						
	Glyphosate	µg/L				30.7	35.6	13

Table K1.2 Descriptive Statistics for Selected Constituents, Influent (cont'd)

	Constituent	Unit	Rest Areas			Vehicle Inspection Facilities		
			Mean	Std Dev	n	Mean	Std Dev	n
Conventionals	TOC	mg/L	22.2	40.5	53	20.0	16.9	31
	DOC	mg/L	19.9	39.6	53	18.5	15.9	31
	EC	µS/cm	78.2	132.0	53	113.3	137.3	31
	Hardness as $CaCO_3$	mg/L	33.0	81.2	53	33.5	22.1	31
	Chloride	mg/L						
	TDS	mg/L	61.2	130.0	53	84.8	92.1	31
	TSS	mg/L	63.3	54.4	53	83.4	53.0	31
	Turbidity	NTU						
Hydro-carbons	Oil & Grease	mg/L						
	TPH (Diesel)	mg/L						
	TPH (Gasoline)	mg/L						
	TPH (Heavy Oil)	mg/L						
Metals	As, dissolved	µg/L	1.4	3.3	53	1.0	0.4	31
	As, total	µg/L	3.6	11.4	53	3.4	16.1	31
	Cd, dissolved	µg/L				0.20	0.16	31
	Cd, total	µg/L	0.32	0.53	53	0.56	0.40	31
	Cr, dissolved	µg/L	1.9	2.5	53	1.8	1.2	31
	Cr, total	µg/L	4.8	3.8	53	8.1	4.8	31
	Cu, dissolved	µg/L	9.6	12.0	53	15.6	13.3	31
	Cu, total	µg/L	16.0	14.2	53	33.6	24.1	31
	Hg, dissolved	µg/L						
	Hg, total	µg/L						
	Ni,dissolved	µg/L	3.2	5.8	53	3.5	2.4	31
	Ni, total	µg/L	7.3	8.3	53	8.4	4.7	31
	Pb, dissolved	µg/L	1.2	1.7	53	2.7	3.9	31
	Pb, total	µg/L	7.7	8.0	53	21.9	37.7	31
	Zn, dissolved	µg/L	82.5	263.7	53	88.2	79.1	31
	Zn, total	µg/L	142.4	298.9	53	244.5	151.6	31
Micro-bio-logical	Fecal Coliform	MPN per 100 mL						
	Total Coliform							
Nutrients	NH_3-N	mg/L						
	NO_3-N	mg/L	0.96	0.88	53	0.89	0.81	31
	Ortho-P, dissolved	mg/L	0.44	1.67	52	0.13	0.12	30
	P, total	mg/L	0.47	0.53	53	0.28	0.16	31
	TKN	mg/L	4.37	14.04	53	2.16	2.72	30
Pesticides Herbicides	Chlorpyrifos	µg/L						
	Diazinon	µg/L						
	Diuron	µg/L						
	Glyphosate	µg/L						

[1] Caltrans. 2003. *Discharge Characterization Study Report. November 2003.* CTSW-RT-03-065.42.
[2] Conductivity unit = µmhos/cm.

Table K1.3 Descriptive Statistics for BMP Percent Removals

	Constituent	Filtration BMPs		Sedimentation BMPs		Biofiltration BMPs	
		Standard Deviation (Range)	COV (Range)	Standard Deviation (Range)	COV (Range)	Standard Deviation (Range)	COV (Range)
Conventionals	TOC	39 (11 – 55)	16 (7 – 32)	18 (12 – 26)	3.3 (1.9 – 4.8)	28 (10 – 403)	2.3 (2.3 – 3.5)
	TSS	26 (5.6 – 52)	0.4 (.06 - 1.0)	26 (9 – 42)	0.5 (0.1 – 1.5)	20 (9 – 186)	2.4 (0.1 – 3.5)
	TDS	73 (8 – 136)	1.2 (0.2 – 2)	31 (10 – 48)	11 (0.5 – 23)	40 (23 – 1281)	3.3 (0.7 – 7.5)
Hydrocarbons	TPH (Diesel)	37 (26 – 51)	1.0 (0.5 - 2)	43 (21 – 52)	4.0 (0.6 – 6.5)	31 (N/A)	0.5 (N/A)
	TPH (Heavy Oil)	25 (13 – 32)	0.5 (0.2 – 1.5)	47 (8 – 63)	3.0 (0.2 – 4)	15 (4.5 – 76)	2.6 (0.1 – 3.6)
Metals	Cd, total	27 (19 – 29)	0.6 (0.3 – 1.6)	35 (27 – 52)	1.4 (0.5 – 2.6)	14 (10 – 61)	0.7 (0.2 – 1.4)
	Cr, total	80 (16 – 134)	8.3 (0.4 – 22)	22 (12 – 28)	0.8 (0.3 – 1.8)	13 (9 – 40)	56 (0.1 – 141)
	Cu, total	28 (24 – 39)	0.9 (0.6 – 2.3)	24 (22 – 28)	0.9 (0.4 – 2.0)	15 (7 – 61)	21 (0.1 – 80)
	Ni, total	55 (27 – 95)	25 (1 – 50)	29 (20 – 37)	0.8 (0.3 – 1.8)	16 (12 – 74)	1.3 (0.2 – 2.6)
	Pd, total	22 (6.4 – 45)	0.3 (0.1 – 1.3)	28 (15 – 47)	1.6 (0.2 – 3.4)	13 (8 – 42)	0.4 (0.1 - 0.8)
	Zn, total	27 (6.6 – 54)	0.5 (0.1 – 1.6)	24 (13 – 37)	0.6 (0.3 – 1.6)	13 (7 – 47)	0.4 (.01 – 1.2)
Microbiological	Fecal Coliform	160 (43 – 436)	2.0 (0.6 – 3.6)	47 (37 – 66)	1.2 (0.7 – 2.5)	20 (14 – 134)	5.7 (1.2 – 16)
Nutrients	P, total	48 (23 – 64)	1.7 (0.5 - 3)	52 (27 – 77)	2.0 (0.6 – 3.4)	19 (40 – 135)	13 (4.4 – 19)
	TKN	46 (25 – 76)	1.3 (0.6 – 2.5)	32 (18 – 47)	4.2 (2.7 - 11)	16 (21 – 53)	21 (3 - 47)

Notes: Data is for mean standard deviation (and range for individual sites) and mean coefficient of variation COV (and range for individual sites). Descriptive statistics are for the actual percent removals and not for influent or effluent data.

Source: Sacramento State Office of Water Programs.

- standards or policy decisions. Typically, Caltrans BMP studies look for a minimum change of 50 percent. In some studies, such as those where BMP effluents are close to regulatory limits, or where the BMPs being studied are thought to be working poorly, detecting smaller Δ values might be appropriate. To be considered for approval, however, a new BMP needs to show a practical level of effectiveness. In most cases, new BMPs would not be approved if they would not be expected to remove at least half of the constituent of concern.
- Desired confidence that the selected statistical test would reach a correct conclusion when the assumed baseline condition is, in fact, true. Typically, the assumed baseline condition would be that the BMP provides no benefit. For example, the average pollutant concentrations in the influent and effluent are the same, or the pollutant removal is 0 percent. The desired confidence is commonly denoted by $(1-\alpha)$, and α is called the probability (or risk) of making a Type I error, or the probability of *false rejection* (i.e., the probability of rejecting the baseline when it is correct). In the context of a typical BMP study, α is the chance that one would claim a BMP is working when, in fact, it does not. Typical values of α for Caltrans stormwater study are 5 percent and 10 percent. Based on common practice, a value of 10 percent is recommended.
- Desired confidence that the statistical test would be able to detect a change of Δ from the baseline condition. This confidence is referred to as the power of the statistical test and commonly denoted by $(1-\beta)$. The parameter β is the probability (or a risk) of failing to detect a specified change. It is also referred to as the probability of making a Type II error, or the probability of *false acceptance* (i.e., the probability of accepting the baseline when it is incorrect). In the context of typical BMP studies, β measures the willingness to miss an opportunity to identify a BMP that does work. Typical values of $(1-\beta)$ for Caltrans stormwater study are 80 percent and 90 percent. Based on common practice, a value of 80 percent is recommended for $(1-\beta)$.

For given values of s, Δ, α, and β, one can calculate the minimum sample size, n. An exact method is available in JMP and other similar software packages, such as Visual Sample Plan developed by U.S. Department of Energy[6]. However, it requires the knowledge of some advanced statistical concepts. A much simpler method that is approximate, but very accurate, is provided in the USEPA guidance document EPA QA/G-9S.[7] The approximate method also assumes a normal distribution. Valid computational simplifications are made as described in the

[6] U.S. Department of Energy. 2005. *Visual Sample Plan Version 4.0 User's Guide*. PNNL-15247.
[7] USEPA. 2006. *Data Quality Assessment: Statistical Methods for Practitioners*. EPA QA/G-9S.

USEPA guidance document EPA QA/G-4, Appendix[8]. The USEPA document EPA QA/G-9S gives the following equation (Equation K1-1) to calculate *n*:

$$n = \frac{s^2\left(z_{1-\alpha} + z_{1-\beta}\right)^2}{\Delta^2} + \frac{z_{1-\alpha}^2}{2} \qquad \text{...........[Equation K1-1]}$$

where n = sample size
s = sample standard deviation
$z_{1-\alpha}$ = value of standard normal variate at 1-α probability
$z_{1-\beta}$ = value of standard normal variate at 1-β probability
Δ = minimum change in the average value of the parameter of interest

USEPA has developed a software program called DEFT (Decision Error Feasibility Trials) that can be used to calculate the sample size, *n*, using Equation K1-1. This program can be downloaded from the following web site: www.epa.gov/quality/qa_docs.html. Figure K1-1 shows plots of *n* derived from Equation K1-1 for some typical values of other parameters. Note that Δ is normalized by *s* in Figure K1-1.

When several constituents are of concern, the above procedure is used for each constituent and the largest sample size is selected.

It is important to understand the influence of the four factors on the sample size selection:

(1) *Influence of Standard Deviation, s.* The sample size increases as the standard deviation increases. This means that if the data were highly variable, it would take a larger number of samples to detect a specified change. It is obviously critical to eliminate or reduce any variability that is under the control of the Project Delivery Team. For example, variability due to different monitoring personnel, equipment, sampling protocols, or analytical laboratories should be controlled through quality control procedures and training.

(2) *Influence of the Minimum Change to Be Detected, Δ.* The sample size increases as Δ decreases. This means that one needs more data if a smaller change is to be detected. The choice of the minimum change to be detected should be made with careful thinking. Comparing current discharges to legal or regulatory standards may provide a logical method to choose this parameter.

(3) *Influence of Confidence Level,* (1-α). The sample size increases as the desired confidence level increases. Values of (1-α) and (1-β) should be selected taking into account the

[8] USEPA. 2006. *Guidance on Systematic Planning Using the Data Quality Objectives Process.* EPA QA/G-4.

consequences of reaching an incorrect conclusion. Typically, the baseline condition is defined such that the consequences of falsely rejecting this condition would be more severe than the consequences of failing to detect the specified change. For BMP studies, the consequences of assuming a BMP is effective when it is not, might be considered to be worse than the consequences of concluding a BMP is ineffective when, in fact, it reduces the pollutant concentration by Δ. If this assumption is reasonable, one should specify a higher value for $(1-\alpha)$ than for $(1-\beta)$. Equivalently, α should be less than β.

(4) *Influence of Power of Detecting the Specified Minimum Change*, $(1-\beta)$. A higher power of detecting a specified minimum change requires a larger sample size.

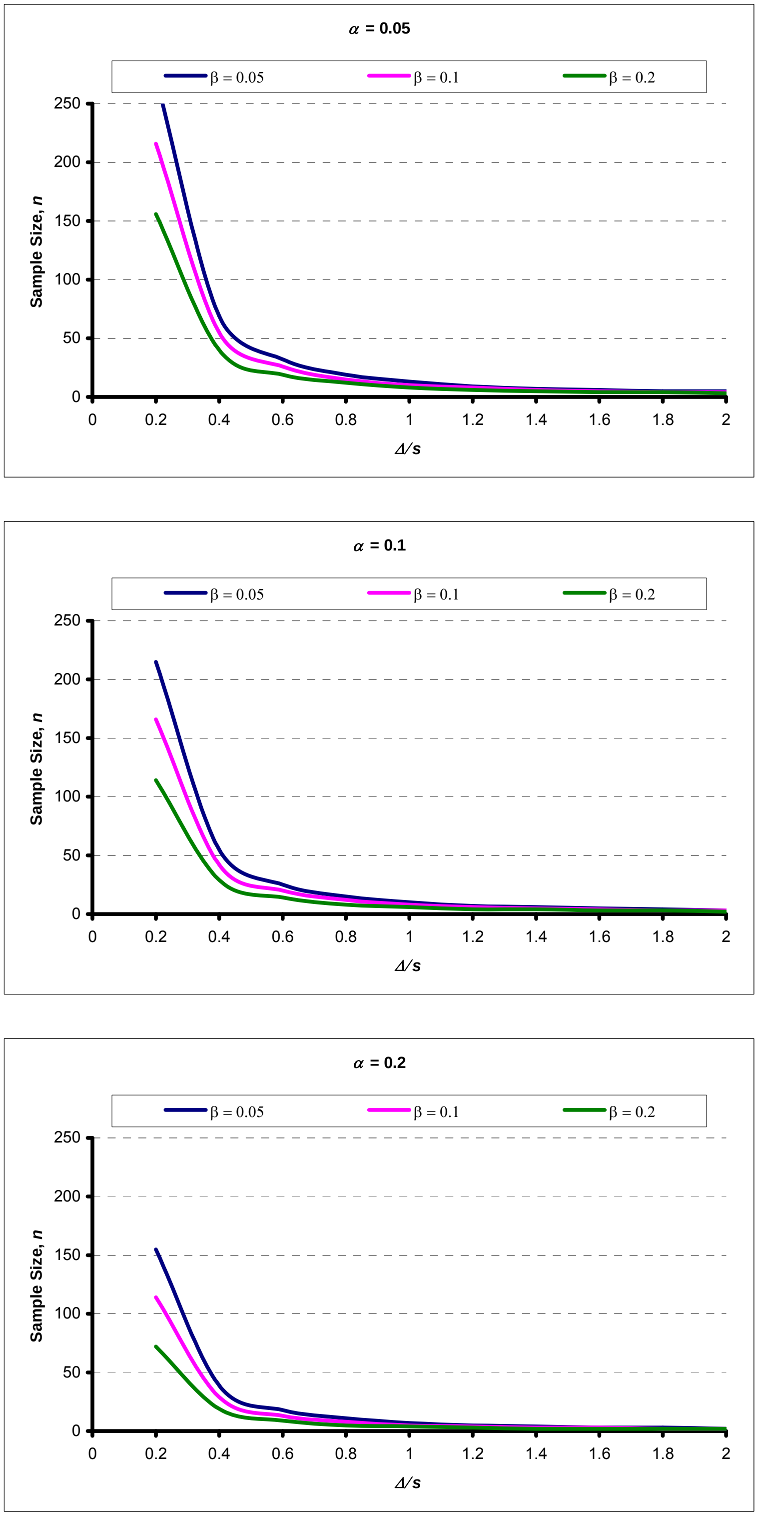


Figure K1-1 Sample Size, *n*, Versus Ratios of Δ/s for Typical Values of α and β – One-population, Normal Distribution

Example K1-1

Assume that effluent zinc concentrations are of concern in a BMP study. The study question of interest is: Does the mean effluent zinc concentration exceed a specified standard by more than 2 mg/L? The expected number of annual independent storm events is 10 and the monitoring period will be 3 years. Based on data on a similar BMP at a similar site, it was assumed that the effluent zinc concentration would follow a normal distribution with a standard deviation of 6 mg/L. The desired confidence for reaching the correct conclusion when the mean effluent zinc concentration was equal to the standard was 0.95 and the desired power of detecting the minimum change of 2 mg/L over the standard was 0.8. How many pilot sites should be selected for this study? Note that for Caltrans studies, the 90 percent confidence level should be used.

For this example, $s = 6$, $\Delta = 2$, $1\text{-}\alpha = 0.95$, and $1\text{-}\beta = 0.8$. Using Equation K1-1, the sample size, *n*, is calculated to be 57. Since 3 years of monitoring is planned with 10 events per year, 2 pilot sites should be selected, which would yield a total of 60 data points. Alternatively, a single pilot site may be monitored for 6 years to obtain the necessary data. If multiple sites are selected, they should be located so as to provide independent, and not redundant, data.

K1.3.2 A Single Data Set with Lognormal Distribution

Environmental variables, such as pollutant concentrations, often exhibit non-symmetric, right-skewed data distributions and hence may be better modeled as a lognormal distribution, rather than the symmetric, normal distribution. If a variable, *X*, is lognormally distributed, its log-transform ($Y = ln(X)$) would be normally distributed. Thus, the procedures described in the preceding section can be applied to the log-transformed variable. The variability of a lognormal variable is commonly expressed in terms of its coefficient of variation, CV_X, which is defined as the ratio (standard deviation, s_X, divided by mean, $\bar{x}$). For this case, the sample size, *n*, depends on the following factors:

- Coefficient of variation, CV_X. In the planning stage, this parameter is estimated based on prior data at similar sites or professional judgment. Refer to Table K1.3 for the coefficient of variation data. The standard deviation of *Y* can be calculated as a function of CV_X using Equation K1-2:

$$s_y = \sqrt{\ln(1 + CV_X^2)} \qquad \text{…………[Equation K1-2]}$$

- Minimum percent change, *p*, in the average value of the parameter of interest (e.g., average percent removal of a specified pollutant). The change in the log space of *Y*, Δ_y, can be calculated from *p* using Equation K1-3:

$$\Delta_y = \ln(1/(1\text{-}p)) = -\ln(1\text{-}p) \qquad \text{…………[Equation K1-3]}$$

- Desired confidence level, (1-α). This parameter is defined in Section K1.3.
- Desired power of detecting the specified change, (1-β). This parameter is defined in Section K1.3.

The parameters s_y, Δ_y, α, and β can then be used in Equation K1-1 to calculate the required sample size, *n*. Alternatively, the USEPA program DEFT could be used to calculate the sample size. Figure K1-2 shows plots of the sample size, *n*, for typical values of other parameters.

Example K1-2

An influent-effluent monitoring approach is planned for a BMP study to address the following study question: Does the BMP remove aluminum concentration by more than 20 percent? The expected number of independent storm events at the study site is 10 per year and a monitoring period of 3 years is selected. Based on data from past similar BMP studies, the percent aluminum removal is assumed to follow a lognormal distribution with a coefficient of variation of 1.2. The desired confidence in reaching the correct conclusion when the percent removal is 0 percent is 0.95, and the desired power of detecting the minimum percent removal of 20 percent is 0.8. How many pilot sites should be selected? Note that for Caltrans studies, the 90 percent confidence level should be used.

For this example, s_y, calculated from Equation K1-2, is 0.944; Δ_y, calculated from Equation K1-3, is 0.223; 1-α = 0.95; and 1-β = 0.8. Using Equation K1-1, the sample size is calculated to be 113. Since 3 years of monitoring is planned with 10 events per year, 4 pilot sites should be selected, which would yield a total of 120 data points. Alternatively, 2 pilot sites may be monitored for 6 years to obtain the necessary data. Again, the pilot sites should be selected to generate independent data.

K1.3.3 A Single Data Set with neither Normal nor Lognormal Distribution

No simple procedure is available to estimate the sample size in this case. Consultation with a statistician may be needed.

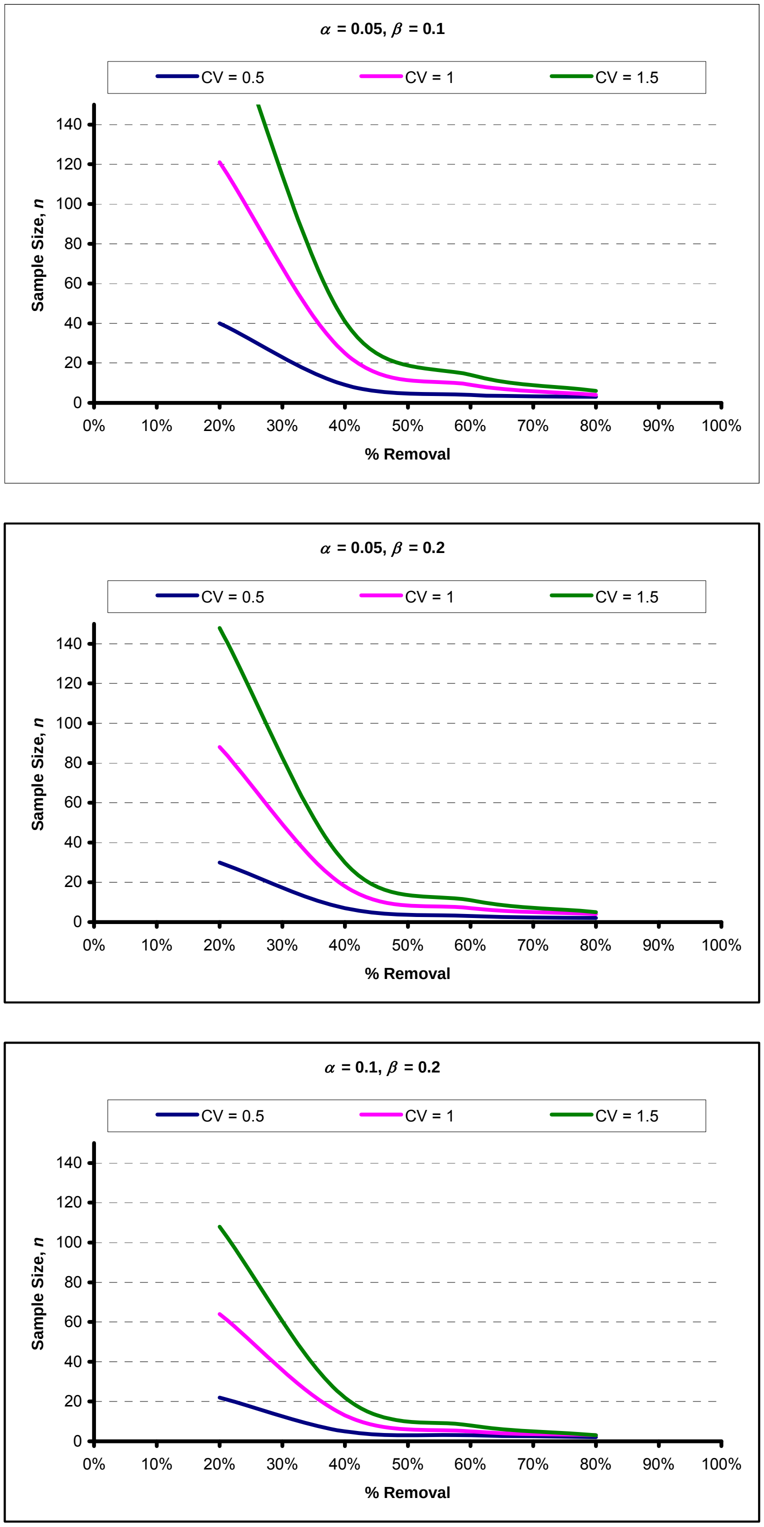


Figure K1-2 Sample Size, *n*, Versus Percent Removal for Typical Values of α and β – One-population, Lognormal Distribution

K1.4 Study Questions Involving Two Independent Data Sets

A typical study question related to two independent data sets is as follows: for pollutant concentrations measured with a paired watershed monitoring approach, is the average pollutant concentration higher in one of the watersheds? The paired watershed approach in this case entails comparison of water quality data from two similar watersheds: one control (undisturbed) watershed and one treatment (disturbed) watershed. However, the specific monitoring stations in the two watersheds are not paired with each other. Thus, the data from the two watersheds define two independent data sets. The procedure to estimate the sample size depends on the data distribution (normal, lognormal, or neither) and whether the variances of the two data sets are equal. As described in Appendix K4, the Shapiro-Wilk W test could be used to test the normality assumption for both the original and log-transformed data. The Levene test, also described in Appendix K4, could be used to test equality of variances. The following cases are considered in this section:

(1) Both data sets follow a normal distribution and have an equal variance.

(2) Both data sets follow a lognormal distribution and have an equal variance in log space (which means an equal coefficient of variation in the original arithmetic space).

(3) Neither normal nor lognormal distribution can be assumed for one or both data sets; or variances are unequal in both original and log-transformed space.

K1.4.1 Two Independent Data Sets with Normal Distribution and Equal Variance

The sample size, *n*, depends on the following factors:

- The common standard deviation of the two data sets, s_p. The following equation can be used to calculate s_p:

$$s_p = \sqrt{\frac{(m-1)s_X^2 + (n-1)s_Y^2}{m+n-2}}$$ …………[Equation K1-4]

where s_p = common sample standard deviation of the two data sets
m = sample size of X
n = sample size of Y
s_X = sample standard deviation of X
s_Y = sample standard deviation of Y

- Since no data would have been yet collected at the planning stage, the standard deviation is typically estimated based on prior data at similar sites or professional judgment. In the interim data review stage (i.e., after collecting data for one or two years), the initial estimate of the standard deviation can be checked and revised if necessary. It should be noted that for typical variables of interest in BMP studies (e.g., pollutant concentrations), the assumption of equal variances is often not valid. For example, if the BMP is effective in reducing pollutant concentration, the effluent concentrations would be lower and the variance is also likely to be smaller. In such a case, the coefficient of variation is more likely to be similar, and the procedure described in the next section may be more appropriate to use.
- The minimum change in the mean value between the two data sets that should be detected, Δ.
- Desired confidence level, (1-α). This parameter is defined in Section K1.3.
- Desired power of detecting the specified change, (1-β). This parameter is defined in Section K1.3.

For given values of s_p, Δ, α, and β, one can calculate the minimum sample size, *n*. Again, an exact method is available in JMP and other similar software packages. However, its use requires knowledge of advanced statistical concepts. A much simpler procedure that is approximate but very accurate is provided in the USEPA guidance document EPA QA/G-9S. The approximate method also assumes a normal distribution and equal variance for the two data sets. Valid computational simplifications are made as described in the USEPA guidance document EPA QA/G-4, Appendix. The USEPA document EPA QA/G-9S gives Equation K1-5 to calculate *n*:

$$n = \frac{2s_p^2\left(z_{1-\alpha} + z_{1-\beta}\right)^2}{\Delta^2} + \frac{z_{1-\alpha}^2}{4} \qquad \text{...........[Equation K1-5]}$$

where n = sample size

s_p = common sample standard deviation of the two data sets

$z_{1-\alpha}$ = value of standard normal variate at 1-α probability

$z_{1-\beta}$ = value of standard normal variate at 1-β probability

Δ = minimum change in the mean value between the two data sets to detect

Note that *n* is the sample size for each of the two groups. The USEPA program DEFT can be used to calculate the sample size using the above equation. Figure K1-3 shows plots of *n* for typical values of other parameters. Note that Δ is expressed in its normalized form; i.e., in terms of the ratio Δ/s_p.

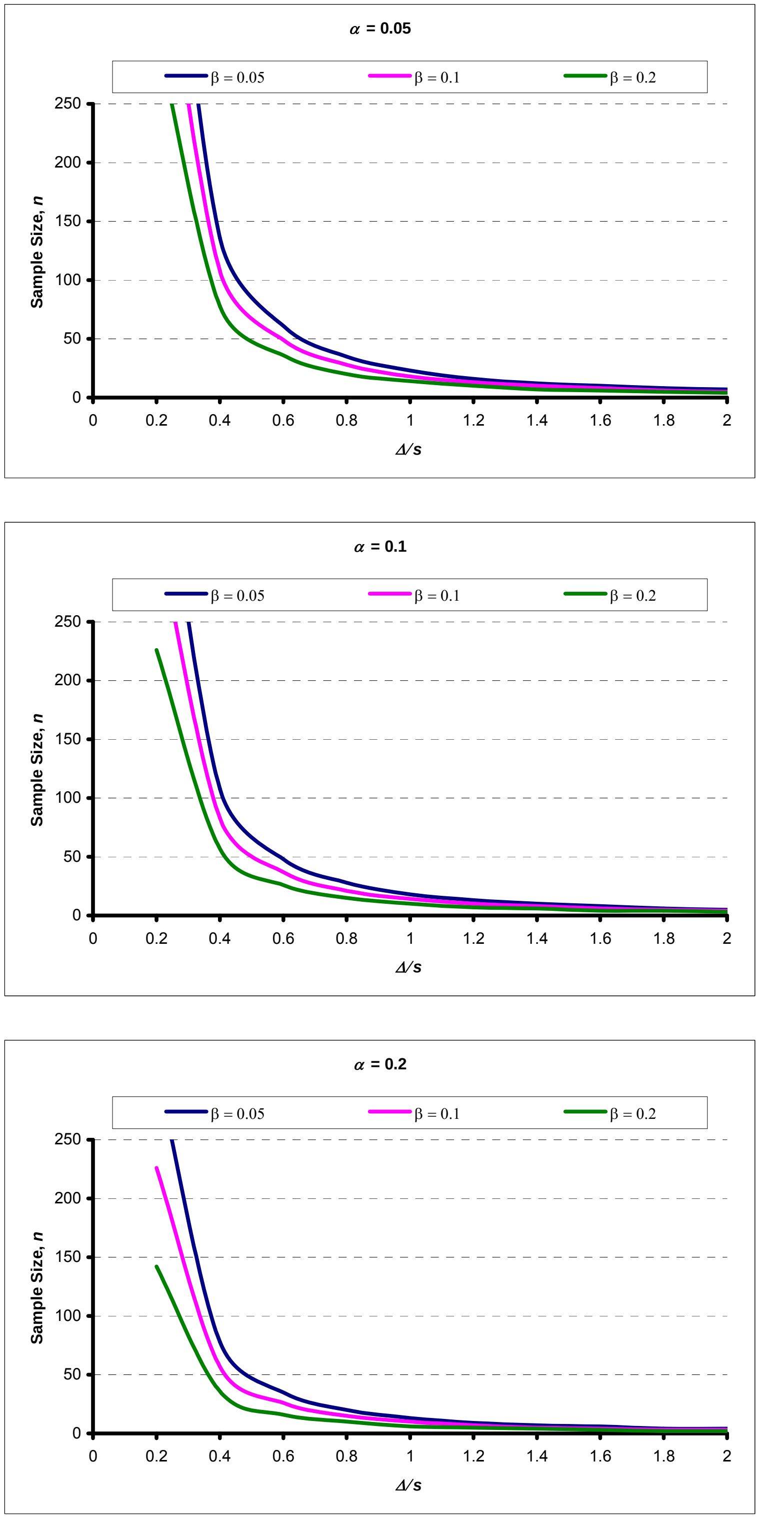


Figure K1-3 Sample Size, *n*, Versus Ratios of *Δ/s* for Typical Values of *α* and *β* – Two-population, Normal Distribution

Example K1-3

A paired-watershed BMP monitoring approach is planned for a BMP study to address the following study question: Is the average aluminum concentration in a treatment (disturbed) watershed higher than that in the control watershed by more than 10 µg/L? The expected number of storm events at the study site is 20 per year. Based on data from past similar BMP studies, the control and treatment watershed data on aluminum concentrations are assumed to follow a normal distribution with a common standard deviation of 20 µg/L. The desired confidence in reaching the correct conclusion when the average control and treatment watershed aluminum concentrations are the same is 0.95, and the desired power of detecting the minimum increase in the average aluminum concentration of 10 µg/L is 0.8. How many years of monitoring should be planned? Note that for Caltrans studies, the 90 percent confidence level should be used.

For this example, s_p = 20 µg/L, Δ = 10 µg/L, α = 0.05, and β = 0.2. From Equation K1-5, the sample size is calculated to be 51 for each of the two groups. Since 20 events per year are expected, 3 years of monitoring should be planned, which would yield a total of 60 data points in each group.

K1.4.2 Two Independent Data Sets with Lognormal Distribution and Equal Coefficient of Variation

As noted previously, data sets in BMP studies are often displayed as right-skewed distributions and can be better modeled as lognormal variables. In addition, the standard deviation of a data set is likely to be proportional to the mean, which means that the coefficient of variation of the two data sets is likely to be the same. If a variable, X, is lognormally distributed, its log-transform ($Y = \ln(X)$) would be normally distributed. If the coefficient of variation of two lognormally-distributed variables is the same, the variances of the log-transformed variables would be the same. Therefore, the procedures described in the preceding section can be directly applied to the log-transformed variables.

The sample size, n, depends on the following factors:

- The common coefficient of variation of the two data sets, CV. In the log space, the common standard deviation of the two data sets, s_{pL}, can be calculated as a function of CV using the following equation (Equation K1-6):

$$s_{pL} = \sqrt{\ln(1 + CV_X^2)} \qquad \text{...........[Equation K1-6]}$$

- The minimum percent change, p, in the mean value that should be detected with high confidence. The change in the mean value in the log space, Δ_L, can be calculated as a function of p using the following equation (Equation K1-7):

$$\Delta_L = \ln(1/(1-p)) = -\ln(1-p) \qquad \text{...........[Equation K1-7]}$$

- Desired confidence level, $(1-\alpha)$. This parameter is defined in Section K1.3.
- Desired power of detecting the specified change, $(1-\beta)$. This parameter is defined in Section K1.3.

For given values of s_{pL}, Δ_L, α, and β, the required sample size can be calculated from Equation K1-5 or using the USEPA program DEFT. Figure K1-4 shows plots of *n* for typical values of the other parameters.

Example K1-4

This example is similar to Example K1-3, except that each data set is assumed to be lognormally distributed with a common coefficient of variation of 1.2. The study question of interest is: Is the average aluminum concentration in the treatment watershed higher than that in the control watershed by more than 30 percent?

For this example, CV = 1.2 (and hence s_{pL} = 0.944), Δ_L = -ln(1-0.3) = 0.357, α = 0.05, and β = 0.2. From Equation K1-5, the sample size is calculated to be 88 for each of the two data sets. Since 20 events per year are expected, 5 years of monitoring should be planned, which would yield a total of 100 data points in each group.

K1.4.3 Two Independent Data Sets with Neither Normal nor Lognormal Distribution; or with Unequal Variances and Coefficients of Variations

The estimation of the sample size for this case requires the use of advanced methods for which consultation with a statistician may be necessary. The USEPA guidance document EPA 230-R-94-004[9] (Section 6.2) describes a rigorous method to estimate the sample size for this case. A more approximate method is included in USEPA guidance document EPA QA/G-9S (Box 3-18 on Page 64).

[9] USEPA. 1994. *Statistical Methods for Evaluating the Attainment of Cleanup Standards.* EPA 230-R-94-004.

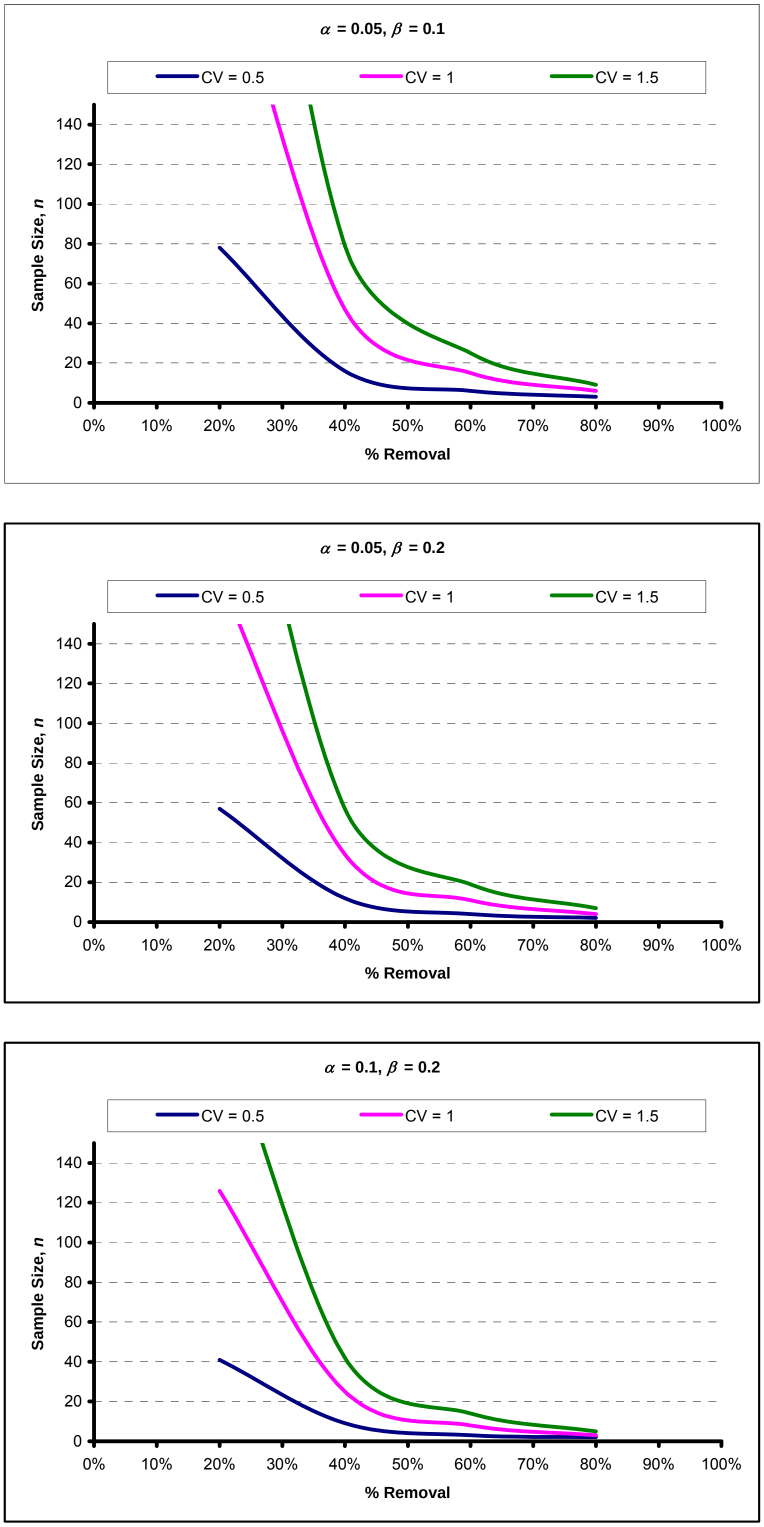


Figure K1-4 Sample Size, *n*, Versus Percent Removal for Typical Values of α and β – Two-population, Lognormal Distribution

K1.5 Study Questions Involving Three or More Independent Data Sets

This topic requires the use of advanced methods, which are not covered in this document. Consult with a statistician to estimate the sample size.

K1.6 Statistical Procedures for Estimating Sample Size in the Interim Data Review

At the planning stage, no actual data would have been collected. Consequently, data from previous similar studies or professional judgment may be used to make assumptions about data distributions and to estimate data variability. After one year of sampling, actual data would be available that should be used for an interim data review to check on the assumptions made during the planning stage and determine whether additional samples, beyond those already planned, would be necessary to meet the study objectives. A minimum of 8 interim data points will be needed to verify assumptions of data distribution and data variability.

For one-population studies (i.e., those involving a single independent data set), the interim data should be used to check whether the data might be assumed to follow a normal or lognormal distribution, or neither. If a normal distribution is appropriate to assume, the interim data should be used to estimate the sample standard deviation. If a lognormal distribution is appropriate to assume, the interim data should be used to estimate the sample coefficient of variation. Using the appropriate data distribution and the estimated standard deviation or coefficient of variation, one should recalculate the necessary sample size and decide whether more samples than initially planned would be necessary to answer the study question of interest.

Example K1-5

We will continue with Example K1-4 involving two independent data sets. During the planning stage, each data set was assumed to be lognormally distributed with a common coefficient of variation of 1.2. After one year of sampling, 20 sample data points were available for each of the two watersheds. The Shapiro-Wilk W test showed that the assumption of a lognormal distribution was reasonable for each data set. Furthermore, the coefficient of variation of each data set was similar, which was estimated to be 1.5. In contrast, the common coefficient of variation was assumed to be 1.2 in the planning stage to calculate the sample size. With the revised estimate of the coefficient of variation, Equation K1-5 yields a sample size of 116 for each watershed. Since 20 samples were collected in the first year, an additional 96 samples would be necessary for each watershed. This would suggest that monitoring would have to continue for 5 more years, instead of 4 more years as initially planned.

Alternatively, one may relax the specification of the minimum percent increase in aluminum concentration that should be detected. For example, specify the minimum percent increase in the average aluminum concentration to be 40 percent, instead of 30 percent specified during the planning stage. With that change, the sample size is calculated to be 57 for each watershed. Thus, an additional 37 samples would be needed for each watershed. This would suggest that, if the revised detection threshold is acceptable, two more years of sampling would be adequate.

Appendix K2 How to Examine Data Quality and Detect Possible Outliers in the Data

K2.1 Purpose and Organization

This appendix presents a collection of graphical and numerical methods that should be used to evaluate data quality and consistency and identify potential outliers in a given dataset. Potential outliers are measurements that are extremely large or small relative to the rest of the data, and, therefore, are suspected of not belonging to the population whose characteristics are being evaluated.

For example, suppose one is trying to evaluate the effectiveness of a particular BMP and the data compiled for the statistical analysis are obtained mostly from that BMP. Additionally, suppose that a few measurements from another BMP are also included in the dataset unknowingly. If the effectiveness of the two BMPs is substantially different, the few measurements from the second BMP may be much larger or smaller than the bulk of the data from the first BMP. The graphical methods presented in this appendix should help in identifying such anomalous measurements. Note that the analysis of the combined dataset from the two BMPs may produce results that are representative of neither BMP.

Potential outliers could also result from transcription errors, data-coding errors, or measurement system problems. Outliers may also represent true extreme values of a distribution that result from a greater variability in the data than expected.

It should be emphasized that outlying or influential observations should not be removed from a data set without explicit confirmation of a measurement error or of other factors that identify the measurement as extraneous to the population of interest. Both the failure to remove true outliers and the removal of false outliers are undesirable outcomes because both could lead to erroneous conclusions. Therefore, the decision of whether to exclude any data should be made with great caution and care.

The next section provides a decision flowchart that identifies the sequence of key steps and decisions to be made based on the results of certain steps. Subsequent sections describe the analysis to be performed in each step, provide guidance in making appropriate decisions, and illustrate the implementation of the step with typical examples drawn from BMP pilot studies.

For this appendix as well as other appendices on statistical analysis, use is made of the statistical software package called JMP, Version 6, developed by the SAS Institute, to produce the graphical plots and numerical results for the analysis of test examples. Any other statistical software package could also be used with generally the same sequence of steps.

K2.2 Decision Flowchart

Figure K2-1 shows a flowchart of the key steps and decisions in examining data quality and identifying potential outliers. The seven key steps are:

1. Compile data in a format suitable for the selected statistical software package.
2. Prepare and interpret graphical displays.
3. Prepare and interpret numerical summaries.
4. Assess whether results of Step 2 or 3 suggest the presence of potential outliers.
5. Check potential outliers identified in Step 4 for specific errors or not being representative.
6. Assess whether any of the potential outliers could be confirmed as actual outliers.
7. Correct or exclude the confirmed outliers from further analysis.

A description of each step follows.

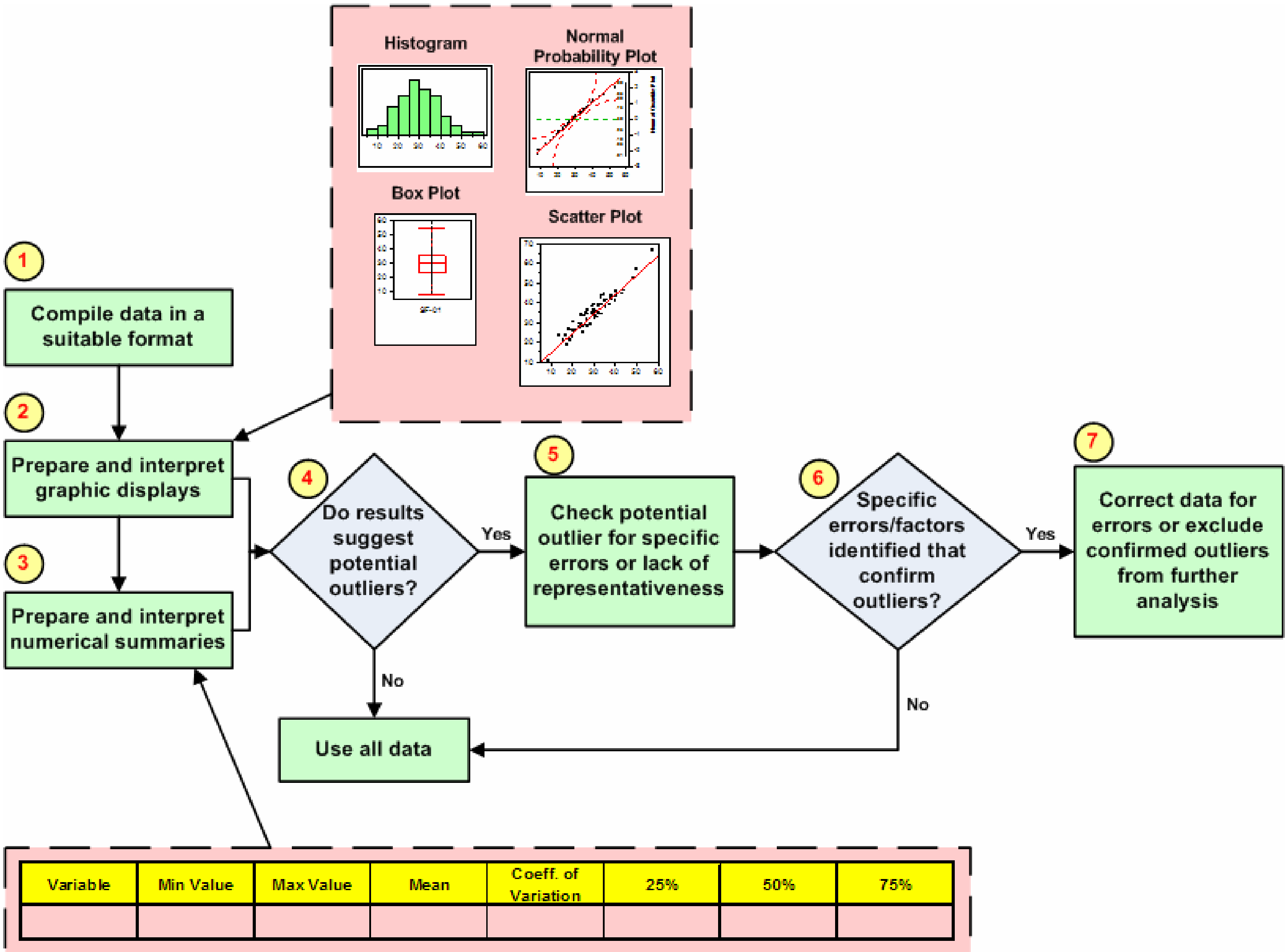


Figure K2-1 Decision Flowchart for Investigating Data Quality and Potential Outliers

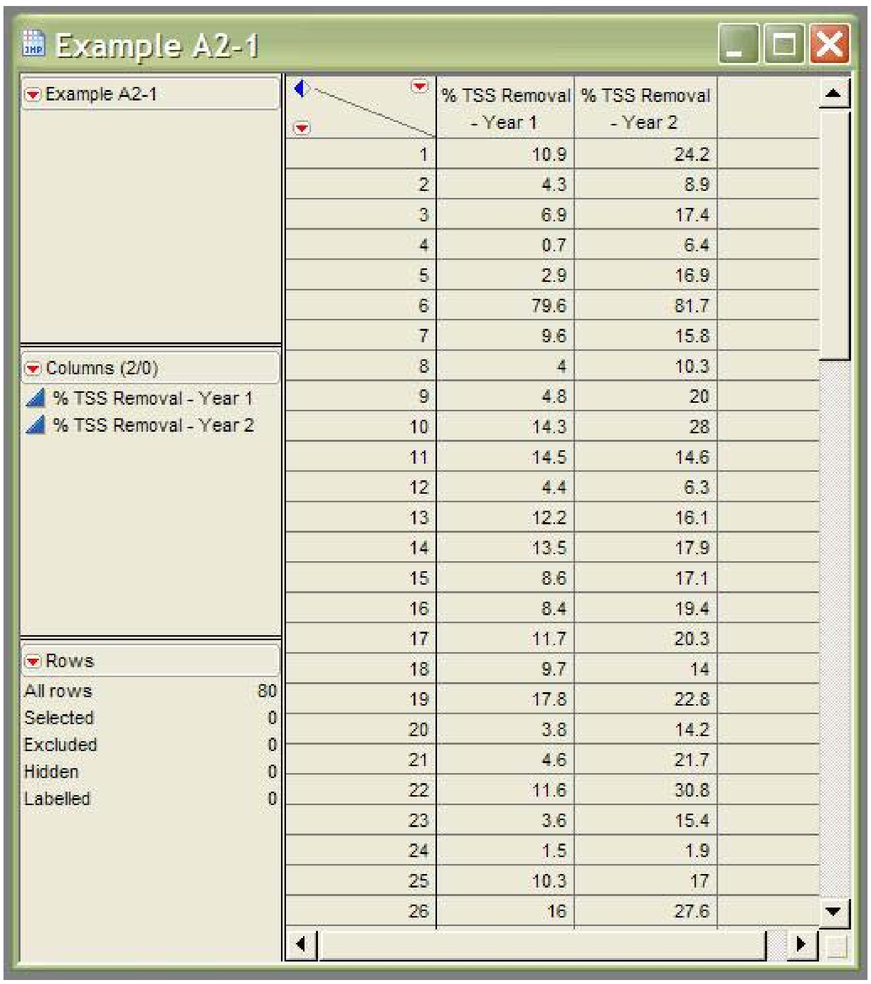
K2.2.1   Step 1. Compile data in a format suitable for the selected statistical software package

Statistical software packages typically use a tabular format for inputting data. The columns represent the different variables that are to be analyzed for quality and each row represents one sample data point. Example K2-1 shown below illustrates the input data table prepared for the JMP software. The same example will also be used to illustrate the results of the subsequent steps.

Example K2-1

Suppose the following data were collected on the percent reduction in total suspended solids from influent to effluent in 80 sand filters in the Los Angeles basin during "Year 1" and "Year 2." It is assumed that, at the end of the storm season in Year 1, these sand filters underwent certain design modifications meant to improve their effectiveness.

The JMP input data table will comprise one row for data from each sand filter and two columns – one for Year 1 and one for Year 2. Figure K2-2 shows the JMP input data table.



	% TSS Removal - Year 1	% TSS Removal - Year 2
1	10.9	24.2
2	4.3	8.9
3	6.9	17.4
4	0.7	6.4
5	2.9	16.9
6	79.6	81.7
7	9.6	15.8
8	4	10.3
9	4.8	20
10	14.3	28
11	14.5	14.6
12	4.4	6.3
13	12.2	16.1
14	13.5	17.9
15	8.6	17.1
16	8.4	19.4
17	11.7	20.3
18	9.7	14
19	17.8	22.8
20	3.8	14.2
21	4.6	21.7
22	11.6	30.8
23	3.6	15.4
24	1.5	1.9
25	10.3	17
26	16	27.6

Figure K2-2 JMP Input Data Table

K.2.2.2 Step 2. Prepare and Interpret Graphical Displays

Graphical displays are prepared in the form of data plots. Three common data plots for a single variable of interest (e.g., TSS removal) are histogram, box plot, and normal probability plot. Conversely, when a relationship between two variables is of interest, a scatter plot is used. For example, one may be interested in analyzing the relationship between TSS removal in two different monitoring years. In this case, a scatterplot between TSS removal for the two years would be of interest. The preparation and interpretation of each data plot are described below. Different data plots often provide information about the same data features. The conclusions drawn from one data plot should be confirmed using information from other data plots. Multiple lines of evidence supporting a particular conclusion increase the confidence in that conclusion.

K2.2.2.1 Histogram

A histogram is a type of bar chart in which the data range is divided into bins, the data is sorted into the bins, and the number of data points (and/or the proportion of data points) in each bin is displayed. Figure K2-3 shows the histogram generated by JMP for the "Year 1" data shown in Figure K2-2. Annotated features of a schematic histogram are also shown in Figure K2-3.

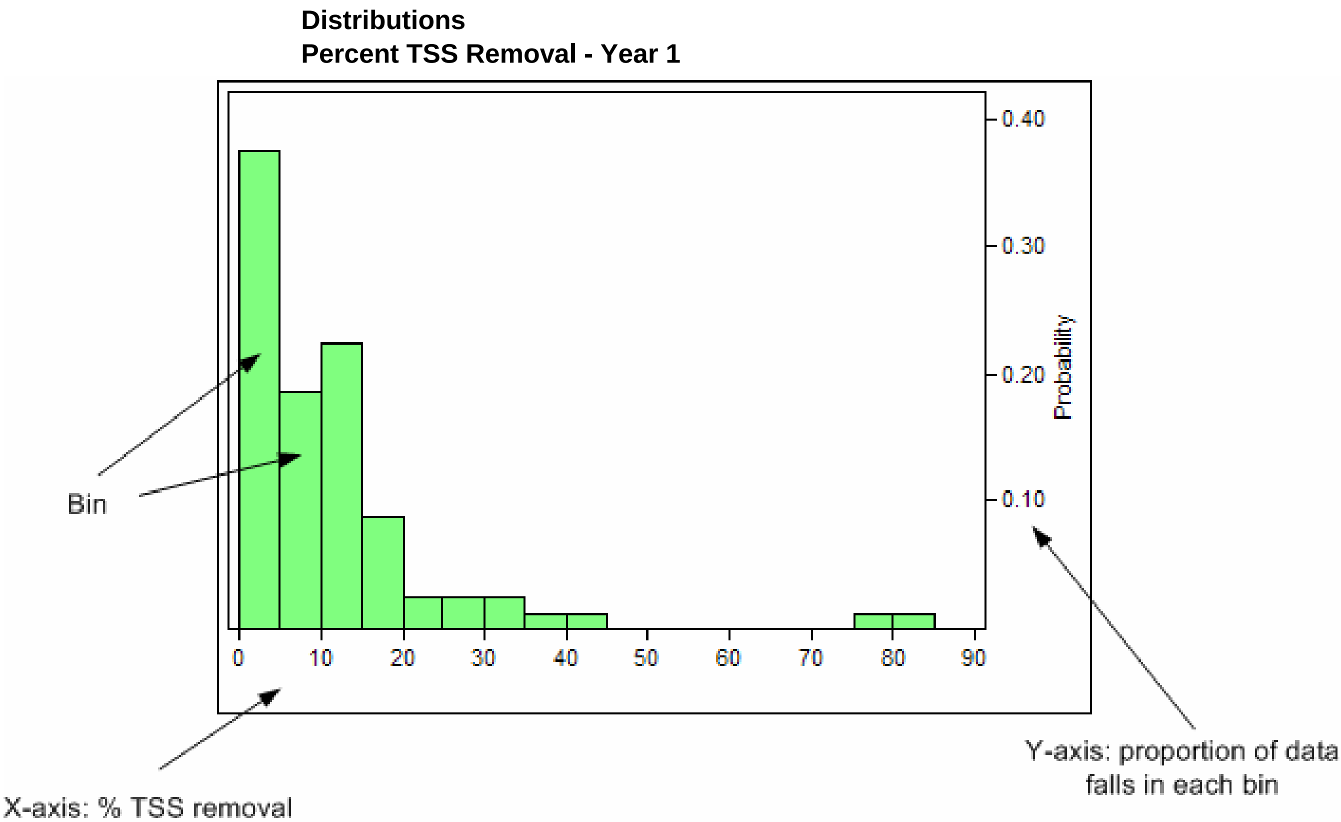


Figure K2-3 Histogram for "Year 1" Data

A histogram is useful in answering the following questions:

1. Does the data distribution have a single "mode" or more than one "mode"?

The mode of a distribution is the value that occurs most frequently and is indicated by the peak of the histogram. Figure K2-4 shows examples of several histograms to highlight different conclusions that could be drawn. Examples of one-mode ("unimodal") and two-mode ("bi-modal") distribution are included.

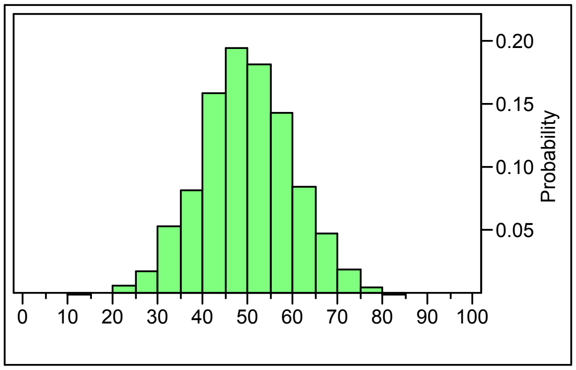
A bi-modal distribution generally suggests the data may be a combination of two separate populations. The use of standard statistical methods that assume a unimodal distribution (such as normal or lognormal) would be inappropriate for a bi-modal distribution.

2. Is the distribution symmetric or skewed?

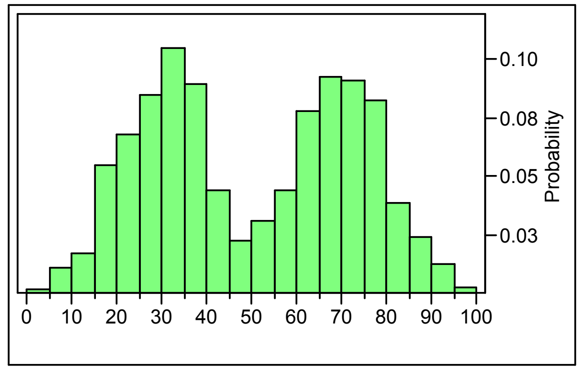
If the histogram indicates a unimodal distribution, one can further check whether the distribution is symmetric or skewed. A skewed distribution typically shows a longer tail on one side of the mode than the other. For water quality data, the distribution tends to be "right" skewed; that is, a longer tail towards higher values. Figure K2-4 shows histograms of symmetric and right-skewed distributions. A normal distribution is symmetric around a single mode. The use of standard statistical methods that assume a normal distribution would be inappropriate for a skewed distribution. A common remedy in case of skewed distributions is a data transformation such as log transformation (i.e., taking natural logarithms of the raw data) that would make the distribution symmetric.

3. Are there potential outliers?

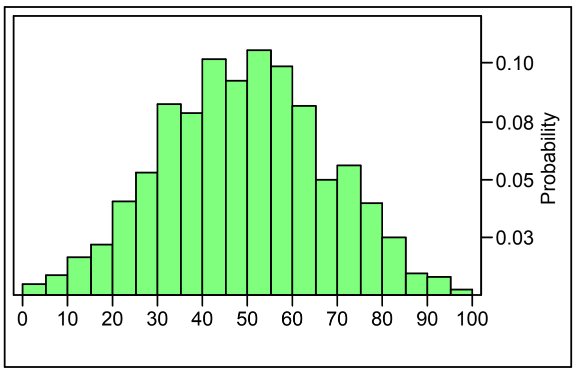
A histogram may show a fairly well-behaved distribution except for some isolated data points that are far different from the rest of the data. Figure K2-4 shows an example of a histogram that suggests one potential outlier.



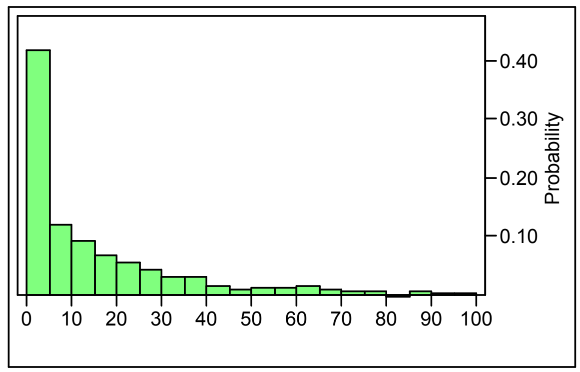
Unimodal Distribution



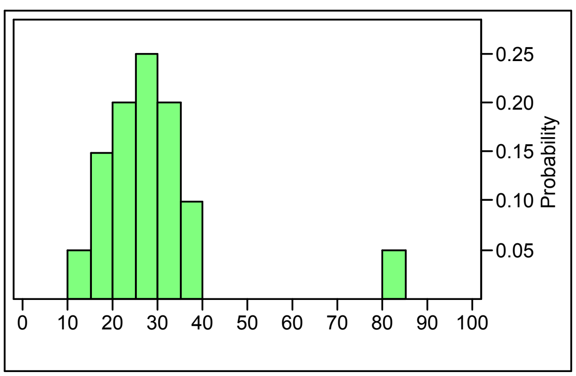
Bi-modal Distribution



Symmetric Distribution



Skewed Distribution



Distribution with Potential Outlier

Figure K2-4 Examples of Different Types of Distribution

Interpretation of the Histogram for Example K2-1

The histogram shown in Figure K2-3 for Example K2-1 reveals the following features:

- The data show a single mode in the range of 0 to 5 percent TSS removal.
- The data distribution is highly non-symmetric with a longer tail towards the higher values.
- Two values greater than 75 percent are well separated from the rest of the data and may be considered to be potential outliers. Some follow-up on those two sand filters and some attempt to confirm the validity of these two measurements would certainly be in order.

K2.2.2.2 Box Plot

In the JMP software package, this type of graphical plot is identified as the "Outlier Box Plot." It is a schematic that displays key aspects of the data distribution and identifies extreme points that could be potential outliers. Another common name for a box plot is a box-and-whisker plot.

A box plot displays key *percentiles* of the data distribution. A *p*-th percentile of a data distribution defines a data value such that *p* percent of all data would be equal to or below that value. Thus, for example, a 75-th percentile would be such that 75 percent of all data would be less than or equal to it. The 75-th percentile is also called the *upper quartile*. Correspondingly, the 25-th percentile is called the *lower quartile.* The difference between the upper and lower quartiles is called the *interquartile range.* The 50-th percentile is commonly referred to as the *median*. Thus, 50 percent of the data would be below the median and 50 percent would be above it.

The JMP software (and other similar software packages) provides the option of plotting the *mean diamond*. This diamond shows the mean and 95 percentile confidence interval around the mean. Note that for Caltrans studies, the 90 percent confidence interval should be presented.

Figure K2-5 shows a box plot for Example K2-1. Annotated features of a schematic box plot are also shown in Figure K2-5.

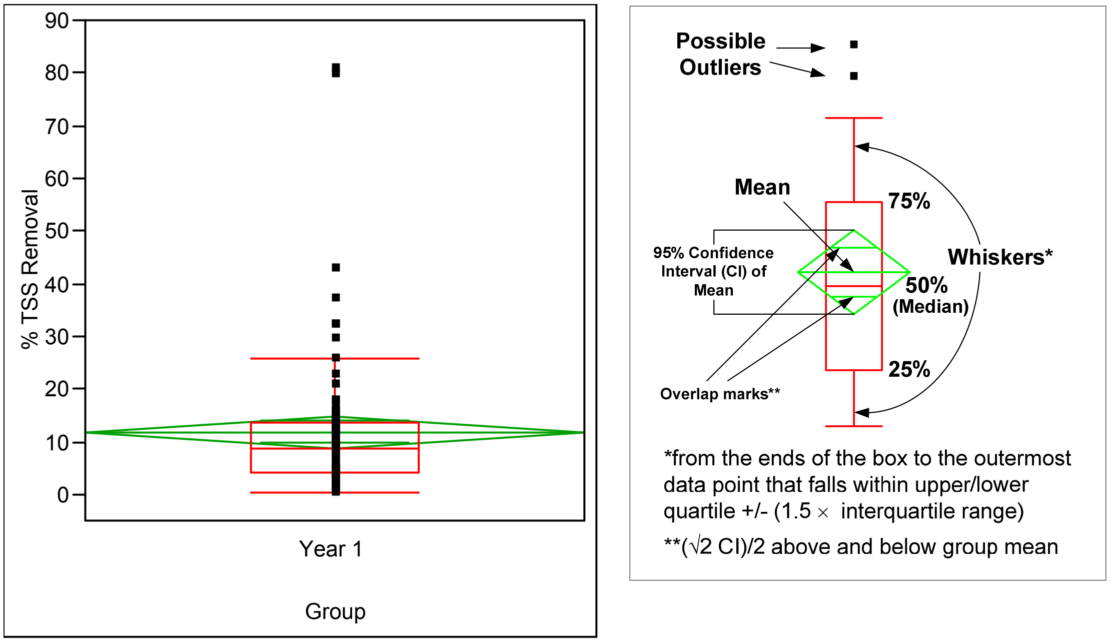


Figure K2-5 Box Plot for Example K2-1

A box plot has a box and lines ("whiskers") drawn on either side of the box. The upper edge of the box is the 75-th percentile and the lower edge of the box is the 25-th percentile. The line inside the box is the median (i.e., the 50-th percentile). On the side of the 75-th percentile, the whisker extends from the end of the box to the highest data point that is still lower than the value of (75-th percentile + 1.5 × (interquartile range)). Similarly, on the side of the 25-th percentile, the whisker extends from the end of the box to the lowest data point that is still higher than the value of (25-th percentile + 1.5 × (interquartile range)). The basic idea is to draw the whiskers such that most of the data would be inside the end points of the whiskers. If any data values do plot outside the end points of the whiskers, they may be considered to be anomalous and hence potential outliers. In the JMP outlier box plot, such potential outliers are shown as dots.

A box plot is useful in answering the following questions:

1. Is the data distribution symmetric or skewed?

If the upper box (above the median) and whisker are approximately the same length as the lower box and whisker, the data are distributed symmetrically. If the upper box and whisker are longer than the lower box and whisker, the data are right-skewed. Conversely, if the upper box and whisker are shorter than the lower box and whisker, the data are left-skewed. A conclusion about data symmetry drawn from a box plot should be checked against that drawn from a histogram.

If the mean diamond is plotted, then the comparison of the mean and median provides an additional check on data symmetry. If the mean and median are about the same, the data are distributed symmetrically. If the mean is greater (lower) than the median, the data are right (left)-skewed.

2. Are there potential outliers?

If any data points plot outside the whiskers (these would appear as dots in the plot outside the whiskers), these may be considered to be potential outliers and require further investigation. Again, information from a histogram of the same data should be used to confirm the presence of potential outliers.

Since the box plot is compact (essentially one-dimensional), several plots for different data sets could be placed on a single graph. This provides a simple, yet very informative tool to compare different groups of data. For example, box plots for different years of BMP performance could be placed on a single graph. Such a graph will provide a quick visual comparison of BMP effectiveness over time. Figure K2-6 provides such a multi-group box plot for Example K2-1. For this example, Year 2 appears to have a higher TSS percent removal.

As noted previously, the mean diamond for each data set (shown in green in Figure K2-6) shows the sample mean and the 95 percent confidence interval around the mean. In addition, horizontal lines are shown inside the mean diamond above and below the sample mean. They provide a simple visual comparison between the means of different data sets. For data sets with equal sample sizes, if the intervals defined by these horizontal lines overlap, the means of the two data sets are not significantly different at the 95 percent confidence level. Note that for Caltrans studies, the 90 percent confidence level should be used.

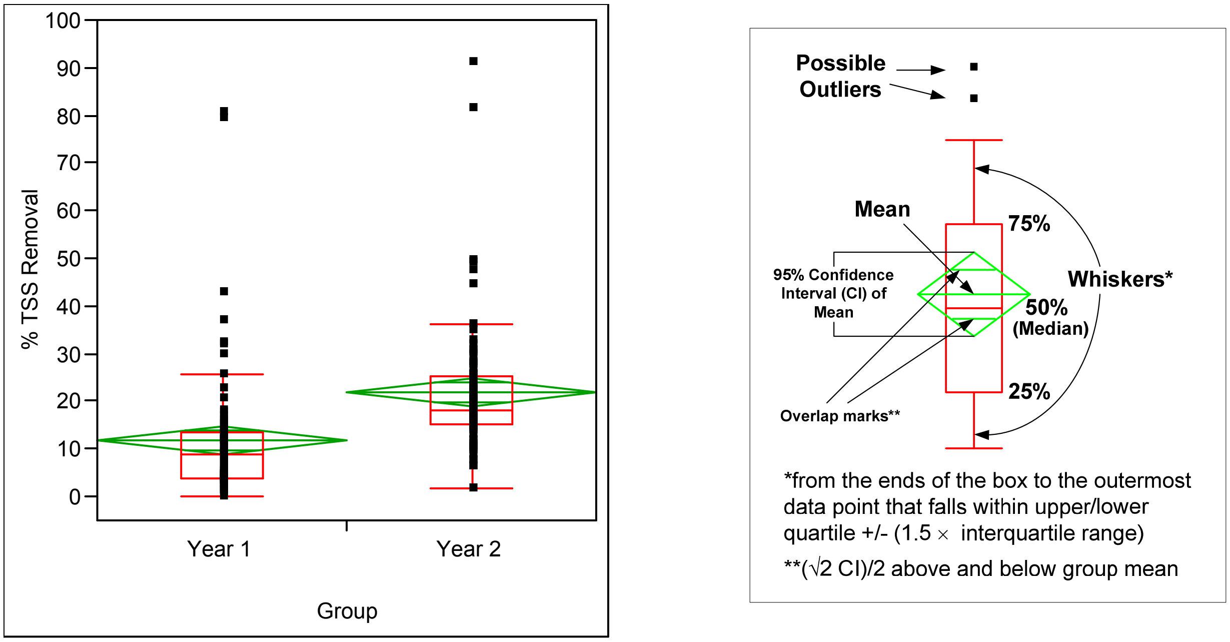


Figure K2-6 Example of Multi-Group Graph of Box Plots

Interpretation of the Box Plot for Example K2-1

The box plot shown in Figure K2-6 for Example K2-1 confirms the two observations made from the histogram; namely, the data distribution is non-symmetric (right-skewed) and there are some extreme values with percent removal around 80 percent.

K2.2.2.3 Normal Probability Plot

Many standard statistical tests assume that the data are normally distributed. It is important to get an early indication of whether this assumption is reasonable. A normal probability plot provides a visual check on the normal distribution assumption.

A normal probability plot is a graph that plots different percentiles of the actual data against the corresponding percentiles of a standard normal distribution. If the graph is approximately linear, this is an indication that the data are normally distributed. This finding should be confirmed with a formal test (formal tests for verifying the normal distribution assumption are described in Appendix K4). Figure K2-7 shows the normal probability plot for Example K2-1.

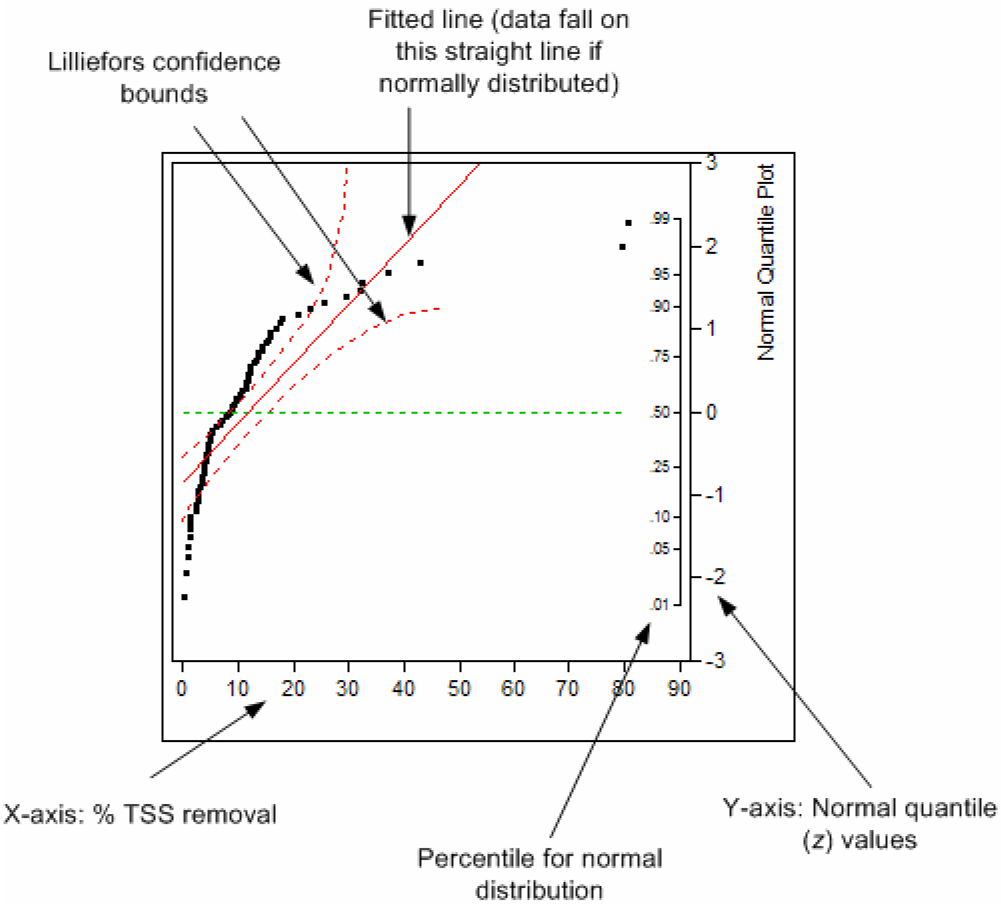


Figure K2-7 Normal Probability Plot for Example K2-1

If the graph is not linear, data may be transformed and a new plot prepared using the transformed data. A common data transformation is the log transformation. Environmental data (such as pollutant concentrations) are often right-skewed. For such data, the normal probability plot would not be linear when the raw data are used, but may become linear when log-transformed data are used. Figure K2-8 illustrates this behavior for Example K2-1.

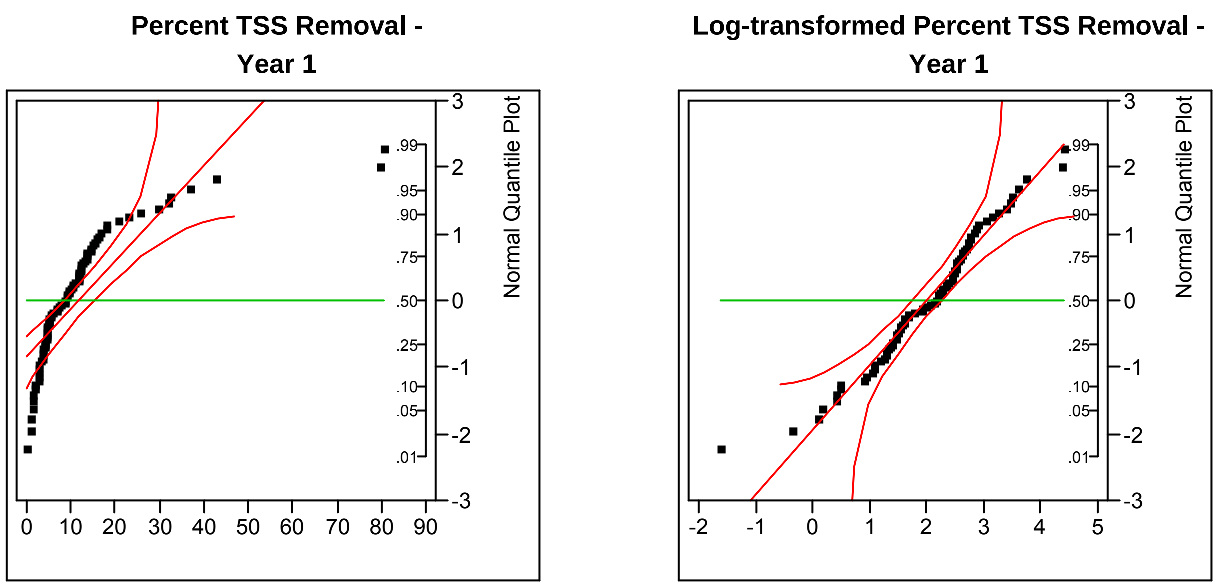


Figure K2-8 Normal Probability Plot for Log-transformed Data

> Interpretation of the Normal Probability Plot for Example K2-1
>
> The normal probability plots shown in Figures K2-7 and K2-8 reveal the following features:
>
> - The plot in Figure K2-7 is strongly non-linear suggesting that the data are not normally distributed.
> - Log-transformed values in Figure K2-8 result in a more linear normal probability plot, suggesting that a lognormal distribution would be more appropriate for these data.

K2.2.2.4   Scatter Plot

This data plot is of interest when one is trying to explore the relationship between two variables. Typical examples include influent-effluent measurements on a particular type of BMP, measurements on a BMP at several sites over two years, or the influence of a particular storm characteristic (such as rainfall intensity) on BMP performance. This data plot helps to answer such questions as: Do the effluent concentrations increase with increasing influent concentrations? Are Year 2 concentrations consistently lower than Year 1 concentrations? Does BMP performance depend on certain storm characteristics?

A scatter plot is a useful graphical tool to visually inspect the relationship or association between two variables that are commonly denoted as Y and X. The variable Y is generally a response variable (such as percent pollutant removal in BMP studies) and X is the explanatory variable that may help explain how Y varies as a function of X. For each value of X, there is a corresponding value of Y. With the common graphing convention, Y values are plotted on the vertical axis and the corresponding X values are plotted on the horizontal axis. The nature of this Y versus X plot reveals if there is a linear or nonlinear relationship between the two variables.

Figure K2-9 shows a scatter plot for Year 2 percent removal versus Year 1 percent removal. Each data point represents information about one specific filter.

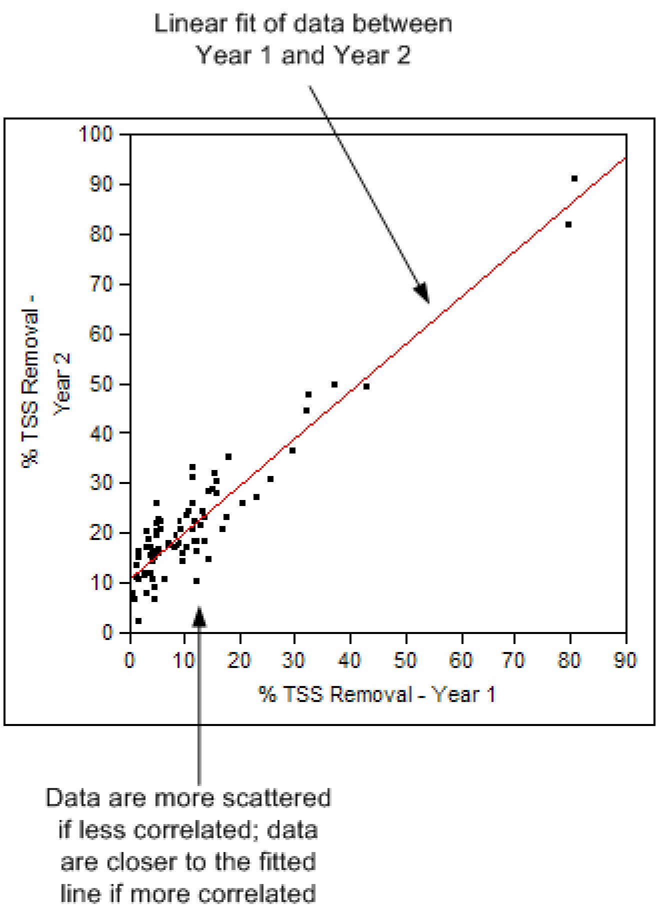


Figure K2-9 Scatter Plot for Year 2 Percent Removal Versus Year 1 Percent Removal

If the pairs of (Y, X) points generally fall on a straight line, this would suggest a linear relationship between the two variables. If the slope of the line is negative, this suggests a negative correlation between the two variables (i.e., Y decreases as X increases). Conversely, a positive slope of the line suggests a positive correlation between the two variables.

If the pairs of (Y, X) points do not plot on a straight line, but do fall on a curve, this would suggest a nonlinear relationship between the two variables. In such a case, it is useful to try different data transformations to see whether the relationship could become linear with some transform. A common transform is the log-transform either on Y, X, or both.

Interpretation of the Scatter Plot for Example K2-1

The scatter plot shown in Figure K2-9 reveals the following features:

- The Year 2 percent removal shows a strong increasing linear relationship with Year 1 percent removal. A sand filter that is performing well in Year 1 seems to be performing equally well or even better in Year 2. This suggests that the design modifications made at the end of Year 1 seem to be working.
- Two of the data points are well separated from the rest of the data. These two points correspond to percent TSS removal around 80 percent in both Year 1 and Year 2, while the maximum percent removal for other points is less than 50 percent. These outlying observations might well be legitimate observations representing conditions in which sand filters are especially effective, but they might also be different because they were taken under different experimental conditions not shared by the other 78 filters. One would want to address the issue of the legitimacy of these points before proceeding with a formal statistical analysis.

K2.2.3 Step 3. Prepare and Interpret Numerical Summary

In addition to the graphical summaries described above, it is useful to prepare a table of statistical measures of the data. Measures of central tendency, data variability, and relative standing provide information about key aspects of data distribution. Definitions of the various measures are provided below. JMP's standard output includes these measures. For equations, the reader is referred to the USEPA guidance document on data quality assessment.[10]

Figure K2-10 shows a summary table of various statistical measures for Example K2-1.

[10] USEPA. Data Quality Assessment: Statistical Methods for Practitioners. EPA QA/G-9S. February, 2006.

Measures of Central Tendency

Group	No. of Data Points	Mean	Median	Mode
% TSS Removal - Year 1	80	11.85	8.75	n/a
% TSS Removal - Year 2	80	21.91	18.30	n/a

Measures of Data Variability

Group	No. of Data Points	Min	Max	Variance	Standard Deviation	Coefficient of Variation	Inter-quartile Range
% TSS Removal - Year 1	80	0.20	80.70	193.36	13.91	117.38	9.63
% TSS Removal - Year 2	80	1.90	91.00	195.43	13.98	63.79	10.08

Measures of Relative Standing

Group	No. of Data Points	5%	25%	50%	75%	95%
% TSS Removal - Year 1	80	1.22	4.03	8.75	13.65	36.77
% TSS Removal - Year 2	80	7.60	15.10	18.30	25.18	49.22

Figure K2-10 Numerical Summary for Example K2-1

K2.2.3.1 Measures of Central Tendency

Measures of central tendency characterize the center of a data set. The three most common measures are the mean, median, and mode. Since these and other measures are calculated using available sample data, they are referred to as sample measures.

The sample mean is the arithmetic average of the data. It is sensitive to extreme values (large or small) and presence of non-detects (See Appendix K3 for methods to deal with non-detects).

The sample median (also called the 50^{th} percentile; see "Measures of Relative Standing" below) is the middle value in an ordered data set. Thus, half the data would be larger than the sample median and half would be smaller. The median is not influenced by extreme values and can be easily computed even if non-detects are present.

The sample mode is the value that occurs with the highest frequency. Since the sample mode may not exist or be unique, this measure is not commonly reported for quantitative data. However, it is useful for qualitative data.

If the sample mean is substantially different from the median, this would suggest a skewed distribution. For environmental data, the mean tends to be higher than the median, indicating right-skewed data.

K2.2.3.2   Measures of Data Variability

Measures of data variability provide information about the spread of values around the center of the data. Common measures include the minimum and maximum sample values (which define the range of the data), sample variance, sample standard deviation, sample coefficient of variation, and sample interquartile range.

The minimum and maximum sample values define the range of the data. The range is not very useful in drawing reliable conclusions from the sample data, because it is greatly affected by extreme values.

The sample variance is the averaged squared distance of the data points from the sample mean. A large sample variance implies that the data are not clustered close to the mean. The sample variance is affected by extreme values and by a large number of non-detects.

The sample standard deviation is the square root of the sample variance and has the same unit of measure as the data. Because it has the same units as the data, the standard deviation might be more easily interpreted and hence is more useful than variance.

The sample coefficient of variation is the relative standard deviation; that is, the sample standard deviation divided by the sample mean. It is unitless and allows the comparison of data variability across different data sets. A sample coefficient of variation of greater than 1 is generally considered to be an indication of non-normally distributed data.

The sample interquartile range is the difference between the 75th percentile and 25th percentile data values. (Recall that a percentile is the data value that is greater than or equal to a specified percentage of the data values). The interquartile range is not much affected by extreme values. When extreme values are present, the interquartile range may be more representative of the data variability than the standard deviation.

K2.2.3.3   Measures of Relative Standing

Measures of relative standing are different percentiles of the data. Commonly reported are the 25th, 50th (also called the median), and 75th percentile values. (Recall these percentiles are displayed in a box plot). For environmental data, higher percentiles (such as 90th and 95th percentiles) may be of interest when only a small percentage of data may be allowed to exceed some standard. Also, the comparison of the maximum (minimum) data value to a high (low) percentile, such as the 95th (5th) percentile is useful in identifying a potential outlier. If the maximum (minimum) value is substantially higher (lower) than the 95th (5th) percentile, the maximum (minimum) value may be a potential outlier.

Interpretation of Numerical Summary for Example K2-1

The numerical summary for Example K2-1 shown in Figure K2-10 reveals the following features:

- The mean is higher than the median for both data sets, suggesting that the data distribution is non-symmetric and right-skewed. This observation confirms the conclusion that was reached previously based on a review of the graphical displays.
- The percent removal is consistently higher for Year 2 for most filters. This is reflected in higher values in Year 2 for mean, median, and most percentiles. In fact, a review of the data for all 80 filters shows that the percent removal is higher in Year 2 for all but one filter.
- The standard deviation is about the same for both years. Since the mean for Year 2 is substantially higher, the relative standard deviation (i.e., the standard deviation divided by the mean, which is shown as the coefficient of variation) is lower for Year 2.

K2.2.4 Step 4. Assess whether results of Step 2 or 3 suggest the presence of potential outliers

If the graphical and numerical methods of data review suggest that some of the high or low data points may be anomalous or inconsistent with most of the data, such points may be considered potential outliers and checked further. If no anomalous or inconsistent data values are identified, all data points should be used in the subsequent analysis.

K2.2.5 Step 5. Check potential outliers identified in Step 4 for specific errors or for not being representative

A data point should not be deleted simply based on the data review without providing specific evidence of a sampling or analytical error or a condition that would make the point non-representative of the population one is trying to study. Examples of specific errors include transcription errors, data-coding errors, sampling equipment malfunction, improper sample collection method, and laboratory errors. A data point may be considered to be non-representative of the BMP being studied if, for example, it was collected for a different BMP.

K2.2.6 Step 6. Assess whether any potential outliers could be confirmed as actual outliers

If the checking in Step 5 reveals a specific, valid reason for concluding that a data point is an outlier, such a data point may be considered to be an actual outlier and appropriate action may be taken as discussed in the next step. If a specific, valid reason is not identified in Step 5, no data point should be removed from further analysis.

K2.2.7 Step 7. Correct or exclude confirmed outliers from further analysis.

If a specific error is identified and the error could be corrected, correct the error and include the corrected data point in further analysis. For example, if a data point is recorded in units different from other data, the data would be recorded in the correct units and used in the subsequent analysis. If a data point is confirmed as being an outlier by physical evidence, field notes, laboratory records etc., and the analysis methods presented herein, but no correctible error is identified, one may exclude this data point from further analysis. Again, discarding an outlier from a data set should not be done without reason, particularly for environmental (such as pollutant concentration) data, which are often skewed and may naturally contain extreme values.

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Appendix K3 How to Examine Data Quality in the Presence of Non-detect Values

K3.1 Purpose and Organization

Pollutant concentration data collected for typical BMP studies often contain a mixture of data – those that are below a detection threshold and those that are above this threshold. The former values are reported as "ND" (for nondetect) or "<MDL," which stands for method detection limit. The latter values are reported as concentrations. Data sets that contain both detect and nondetect values present special difficulties in estimating summary statistics (e.g., mean and standard deviation) and performing statistical tests of group comparison. In the statistical literature, data containing nondetects are called "censored" data.

This appendix describes the difficulties encountered when a data set contains nondetect values and presents methods to deal with these difficulties. An informative reference for this subject is a book by Helsel[11] that presents several methods, ranging from simple to advanced, for incorporating nondetects into the statistical analysis. Helsel's methods will be referenced throughout this appendix. This appendix includes methods specifically related to data quality review in the presence of nondetects. The use of these methods is illustrated with examples relevant to BMP studies. Appendices K5 through K10 include methods for performing specific statistical tests in the presence of nondetects.

K3.2 Difficulties Introduced by the Presence of Nondetects

When nondetects are present in a data set, common statistical quantities (e.g., sample mean and standard deviation) cannot be computed and common statistical methods of group comparisons cannot be applied without making assumptions about the nondetects. A common method to deal with this issue is the "substitution" method in which the nondetects are replaced with a constant value such as half the detection limit. The fundamental problem with this approach is that it assumes something is known (the values for nondetects) that is really not known. The choice for the substitution value is arbitrary, whether it is half the detection limit, equal to the detection limit, or zero, and the conclusions can be quite sensitive to that choice. Furthermore, the effect

[11] Helsel, Dennis R. 2005. *Nondetects and Data Analysis. Statistics for Censored Environmental Data.* John Wiley & Sons. New Jersey.

of using a particular substitution value on the conclusion is unpredictable. For example, the sample mean could overestimate or underestimate the true mean depending on the nature of the data for the same substitution value.

K3.3 Methods of Data Quality Review in the Presence of Nondetects

This section discusses the methods used to prepare the graphical and numerical summaries described in Appendix K2 for data containing nondetects. Example K3-1, shown in Figure 3-1, will be used to illustrate the methods. The data are arsenic concentrations (micro-grams/liter) in the BMP effluent.

<1.8	2.1	4.2
<1.8	2.2	4.2
<1.8	2.2	5.5
<1.8	2.4	5.8
<1.8	2.6	6.0
<1.8	3.1	6.4
<1.8	3.6	6.8
<1.8	3.6	7.1
<1.8	3.9	7.9
<1.8	4.0	8.8

Figure K3-1 Data of Example K3-1

K3.3.1 Recommended Graphical Methods

A histogram, box plot, and normal probability plot are the recommended graphical methods. Although the three data plots are somewhat redundant, all three should be prepared because they help reinforce the conclusions drawn from any single plot.

K3.3.1.1 Histogram

For purposes of a histogram, all nondetects are grouped in a single bin and highlighted in the histogram. For example, one could set all nondetects equal to the detection limit and define the first bin for the histogram to be 0 to the detection limit. Keep in mind that this bin may also contain any detect values that are less than the detection limit. However, for purposes of understanding the key features of the data distribution, this should not be a problem.

Figure K3-2 shows a histogram for Example K3-1. The data distribution is non-symmetric (right-skewed) and does not appear to fit a normal distribution.

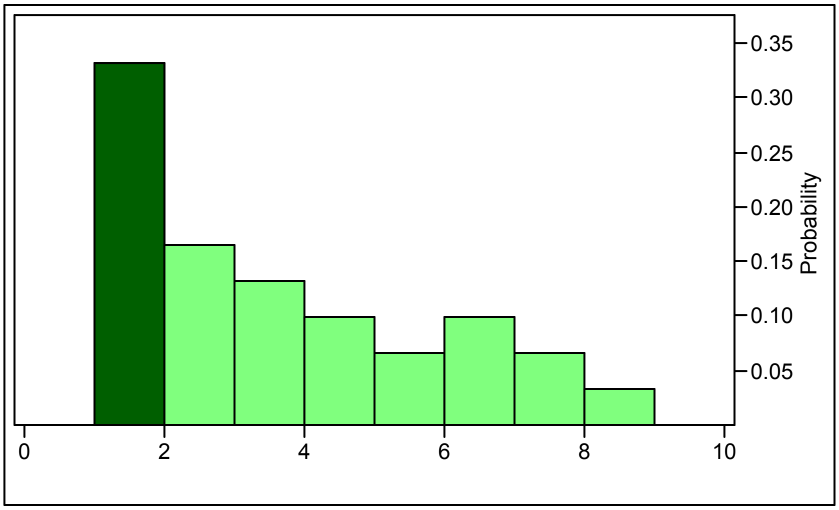

Figure K3-2 Histogram of Arsenic Concentrations in µg/L for Example K3-1 (nondetects shown in the first bin with darker color)

K3.3.1.2   Box Plot

Similar to the histogram, data for a box plot are prepared by setting all nondetects equal to the detection limit. If the data contain *p* percent nondetects, then one cannot estimate a percentile lower than the *p*th percentile. However, percentiles higher than the *p*th percentile can be estimated without making any assumption about specific values for nondetects. In the box plot, the portion dealing with percentiles that can be estimated (i.e., percentiles higher than the *p*th percentile) is shown, while the portion dealing with percentiles lower than *p*th percentile is not shown. Such a display helps focus on the valid percentile estimates at the higher end of the data, while not displaying any information about the lower end that is not supported by the data.

Figure K3-3 shows a box plot for Example K3-1. The plot shows that the percentage of data below approximately 2 micro-grams/liter cannot be estimated with any reliability. However, the percentage of data above this level can be estimated without making any assumptions about the nondetects.

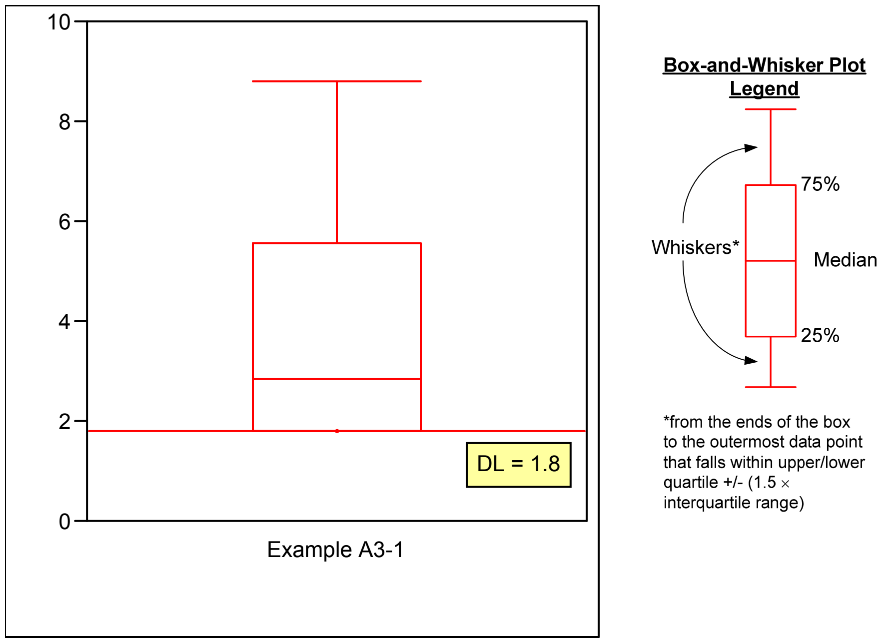

Figure K3-3 Box Plot of Arsenic Concentrations in µg/L for Example K3-1

K3.3.1.3 Normal Probability Plot

As described in Appendix K2, a normal probability plot is useful to assess whether the data (original or log-transformed) follow a normal distribution. When the data contain nondetects, the preparation of such a plot presents a problem. Because the actual value of a nondetect is unknown, only its upper-bound is known, one cannot assign the position of a nondetect on the X-axis. Consequently, a point corresponding to a nondetect cannot be plotted.

In his book, Helsel describes a graphical method to prepare a normal probability plot for censored data. Figure K3-4 shows normal probability plots for original and log-transformed data for Example K3-1 using the Helsel method. Note that only the detect values are plotted, but the plotting positions of those values depend on the percentage of nondetects. The normal probability plot for log-transformed data shows a better linear fit than the original data. Therefore, lognormal distribution is a more reasonable distributional assumption for the data.

When the data contain multiple detection limits, the probability plotting method becomes more complicated. The method is described in greater detail in Helsel's book. Consult with a statistician if assistance is needed to apply this method.

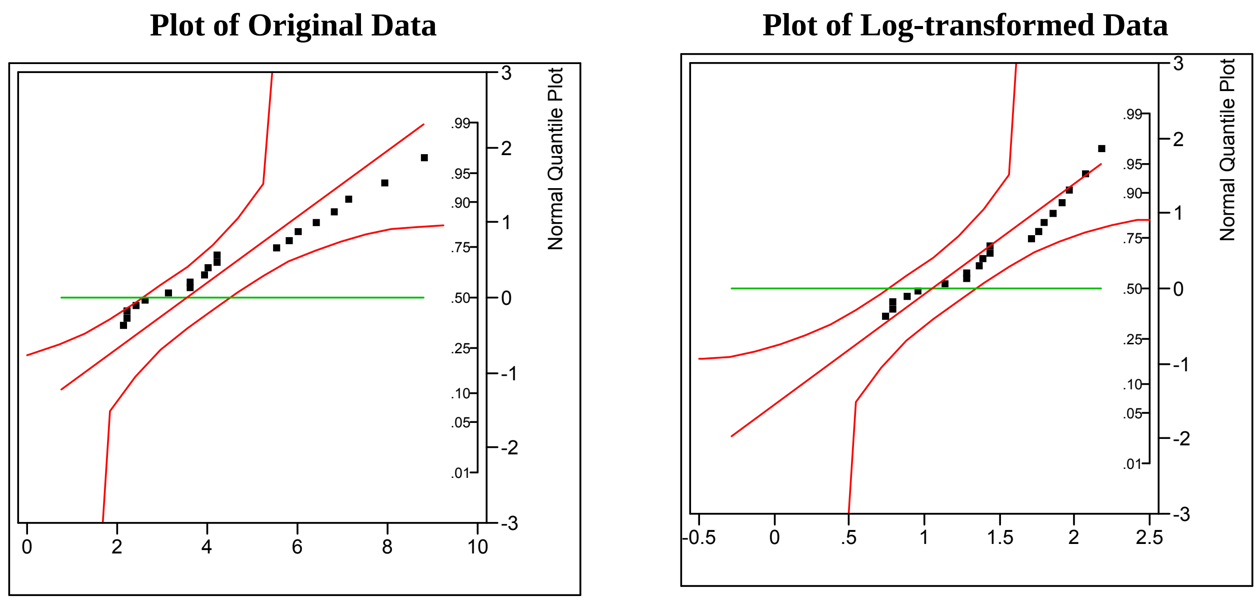

Figure K3-4 Normal Probability Plot of Arsenic Concentrations in µg/L for Example K3-1 (only the detect values are plotted)

K3.3.2   Recommended Method for Preparing Numerical Summaries

The recommended method for preparing numerical summaries depends on the percentage of nondetects, the number of detects, and whether the censored data (original or log-transformed) follow a normal distribution.

If the percentage of nondetects is greater than 80 percent, no method would generate reliable numerical summaries. For this case, one should only report the percentage of data above a meaningful threshold (such as a legal standard).

If the percentage of nondetects does not exceed 80 percent, there are at least three detects, and the censored data (original or log-transformed) follow a normal distribution, the use of the robust Regression on Order Statistics (ROS) is recommended. Caltrans has developed a Data Analysis Tool (DAT) for the implementation of the ROS method. However, it does not check on the normality of the censored data. The method described in the Helsel book (pages 45-47) should be used to prepare a normal probability plot. If the plot shows that the detect values reasonably fit a straight line, the censored data may be assumed to follow a normal distribution and the robust ROS method should be applied. The numerical summaries may be obtained using the Caltrans DAT. A useful enhancement to the Caltrans DAT will be the preparation of a normal probability plot for censored data.

If the percentage of nondetects does not exceed 80 percent and there are fewer than three detects or the censored data do not follow a normal distribution, the use of the Kaplan-Meier (K-M) method is recommended. The K-M method is available in commercial statistics software packages including JMP and Minitab. However, the use of the method requires a rearrangement of the data to fit the format of the particular software package. The user should follow Helsel's instructions (page 63 of his book) to transform the data, use JMP or Minitab to generate results, and then back-transform the results to the original scale.

K3.3.3 Method to Avoid for Preparing Numerical Summaries

The USEPA guidance document[12] suggests substituting nondetects with half the detection limit when the percentage of nondetects is relatively small (less than 15 percent). With this approach, the calculation of numerical summaries is no different for censored data than for non-censored data. Appendix K2 discusses the calculation of numerical summaries for non-censored data. The same methods would apply for a censored data set after the nondetects are replaced with half the detection limit.

However, Helsel performed extensive testing of several alternative methods for the calculation of summary statistics, including the substitution method. Based on this research, Helsel strongly recommends that the substitution method should be avoided in all cases, because better methods are available.

Results for Example K3-1

Figure K3-5 shows the common statistical quantities computed for Example K3-1 using the robust ROS method. For contrast, the figure also shows the same quantities computed using the substitution method in which the nondetects are replaced with half the detection limit. As shown in Figure K3-5, the estimated mean and standard deviation, and 10-percentile and 25-percentile values for the two methods are different. Conversely, the median, 75-percentile, and 90-percentile are the same. This is a reflection of the fact that nondetects constitute 33 percent of the data.

[12] USEPA. 2006. *Data Quality Assessment: Statistical Methods for Practitioners*. EPA QA/G-9S.

Summary Statistics Using the Robust ROS Method

No. of Data Points	Percent NDs	Mean	Std Dev	10%	25%	Median	75%	90%
30	33.3%	3.56	2.26	1.127	1.725	2.85	5.575	7.07

Summary Statistics Using the Substitution Method

No. of Data Points	Percent NDs	Mean	Std Dev	10%	25%	Median	75%	90%
30	33.3%	3.38	2.43	0.9	0.9	2.85	5.575	7.07

Figure K3-5 Statistical Quantities Computed for Example K3-1 Using the Robust ROS Method and the Substitution Method

K3.3.4   Other Methods for Preparing Numerical Summaries

If one is interested only in estimating certain percentiles of a dataset, a method simpler than either the robust ROS or the K-M method is available. The simpler method is to include in the numerical summaries only the percentiles that could be estimated directly from the data. Statistical quantities such as the sample mean and standard deviation would not be reported. This *percentile* method will not provide as much information as either the robust ROS or K-M methods. However, the results generated would not assume any information that is not present in the data, and the results would still provide useful insights into higher values in the data distribution. For example, the percentile method will be valid to use to address the following question: What is the concentration that would be exceeded no more than 10 percent of the time?

If the percentage of nondetects is *p* percent, then one only estimates percentiles higher than *p* percent. For example, if a data set contains 40 percent nondetects, one estimates percentiles higher than 40 percent. Thus, for this example, one would only show the 50th and 75th percentiles and the maximum value in the numerical summary table.

The data set for Example K3-1 contains 33 percent nondetects. Therefore, only percentiles above 33 percent could be directly estimated without making any assumption about the nondetects. For this calculation, all nondetects are set equal to a value less than the smallest detected value. The values of 50 percent, 75 percent, and 90 percent are shown in Figure K3-5.

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Appendix K4 How to Verify Common Assumptions for the Selection of an Appropriate Statistical Test

K4.1 Purpose and Organization

The purpose of this appendix is to present methods to verify common assumptions made in statistical tests so that an appropriate test can be selected. For example, a standard category of statistical tests called *parametric* tests assumes that the data are normally distributed. If the data strongly deviate from this assumption, a parametric test should not be used. Instead, one should use a test drawn from the alternative category of *nonparametric* tests.

Methods to verify the following assumptions are presented in this appendix:

1. Data are independent (i.e., *random*) in time and space.
2. Data (original or transformed) follow a normal distribution.
3. Data (original or transformed) from different groups have the same variance.

Examples are presented to illustrate the application of the methods. As with other appendices, the JMP statistical software package is used to display the results of applying different methods.

K4.2 Verification of Data Independence

An important assumption in standard statistical tests is that the sample data are independent in time and space. The assumption of independence means that each data point is drawn randomly from some distribution and the data value does not depend on any other data value(s). Independent data do not show any correlation in time or space. It is important to verify that the data are independent. If the data are not independent and the statistical test assumes that they are, the confidence of reaching the correct conclusion could be substantially lower than what is implied by the results of the statistical test.

For BMP studies, the number of sampling (monitoring) locations is generally small and hence the sample data may not be sufficient to verify the spatial independence assumption. The monitoring stations should be selected carefully, making sure that they are sufficiently apart from each other so that they can be assumed to be spatially independent. If pilot data were available, one could assess the correlation coefficient between the measurements at adjacent sampling locations. If the correlation coefficient is relatively small (say, less than 0.5), the data from these locations could be assumed to independent.

At each monitoring location, data would be collected for each storm event that meets certain criteria over a period of 2 to 3 years. Therefore, sufficient data should be available to verify the time independence assumption. A recommended method is to prepare a time series plot that shows a graph of measurements versus time interval (e.g., the number of days from the study start date). Such a plot could be prepared using Excel graphing functions. Independent data should show a plot with no structure (i.e., a random “white noise” pattern). A visual examination of such a plot can reveal whether the data show any strong time dependencies. For example, whether there is a trend over time (trend analysis methods are presented in Appendix K10) or whether there is a clustering of high and low values (e.g., one year shows successive high values and the next year shows successive low values). Figure K4-1 shows a schematic of different structures of a time series plot. Independent data should show a plot similar to the one illustrated in Figure K4-1(a).

Data that do show time dependencies should not be combined and treated as one single data group (i.e., one statistical *population*). For example, assume that the effectiveness of a particular BMP improves with time. In such a case, a time series plot of the percent pollutant removal versus time would likely show an increasing trend. For statistical analysis of this data set, one may need to separately analyze the data for each monitoring year.

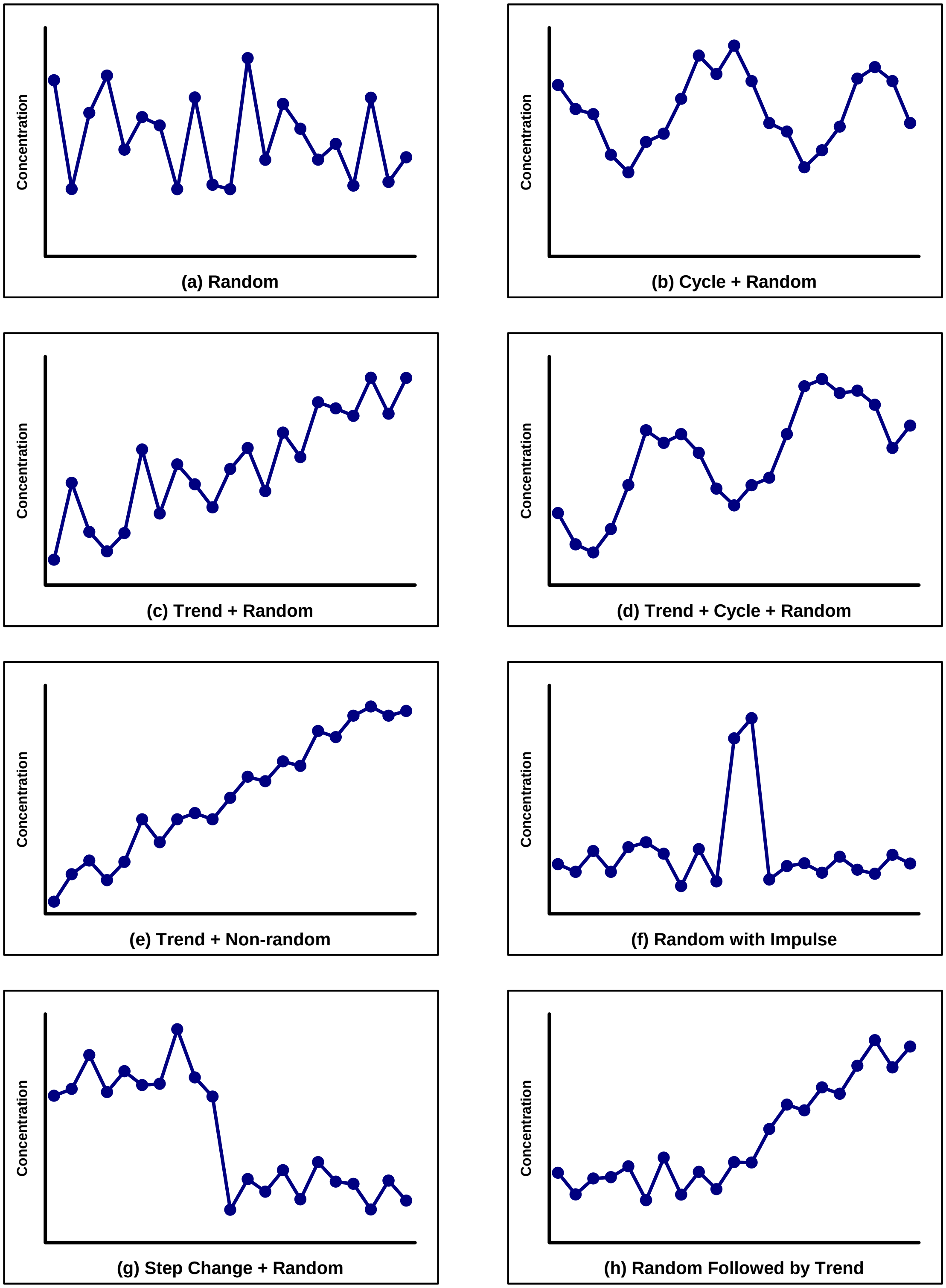


Figure K4-1 Different Structures of Time Series Plot

(Source: Gilbert, Richard O. 1987. *Statistical Methods for Environmental Pollution Monitoring*. Van Nostrand Reinhold, New York.)

Example K4-1

Assume that for an upstream-downstream monitoring program, the upstream dissolved aluminum concentrations (shown in Table K4.1) were measured over a period of 2 years. Figure K4-2 shows a time series plot of this data using Excel. The plot shows no evidence of any particular structure or pattern, or time trend. Data values appear to be randomly distributed above and below an average value. Given these observations, the assumption of time independence for this data set would be reasonable.

Table K4.1 Example K4-1 - Upstream Dissolved Aluminum Concentrations Measured Over a Period of 2 Years

Date	Upstream Dissolved Aluminum Concentrations (mg/L)
1/5/2005	12.5
2/8/2005	10.34
3/1/2005	3.09
4/15/2005	13.66
5/10/2005	1.8
6/4/2005	12.64
7/6/2005	10.79
8/8/2005	5.5
9/2/2005	10.04
10/10/2005	6.4
11/11/2005	3.82
12/2/2005	6.67
1/2/2006	15.74
2/12/2006	5.23
3/5/2006	8.36
4/10/2006	8.5
5/12/2006	7.93
6/7/2006	12.78
7/3/2006	2.25
8/4/2006	9.73
9/11/2006	6.39
10/7/2006	14.67
11/15/2006	5.74
12/10/2006	8.25

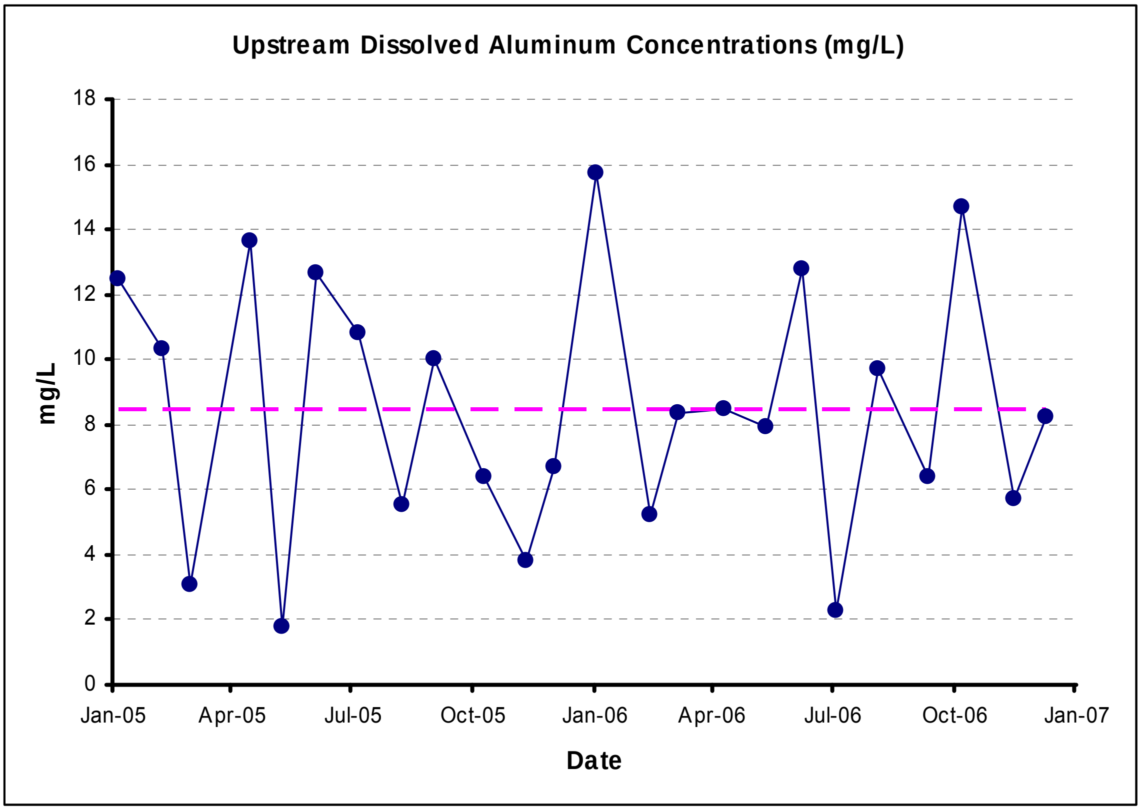


Figure K4-2 Time Series Plot of Example K4-1

K4.3 Verification of Normal Distribution

Many standard statistical tests come from the category of *parametric* tests. Appendices A5 through A8 present several parametric tests that are used to answer specific study questions. A critical assumption for parametric tests is that the data follow a specific probability distribution. The most common probability distribution used in these tests is the *normal distribution* that takes the familiar shape of a bell-shaped symmetric distribution. The normal distribution may be assumed for either the original or transformed data. Environmental data are often non-symmetric (typically right-skewed or long tails towards higher values). For such data, log transformation is commonly used to produce a data distribution that is symmetric and more likely to follow the normal distribution. If the log-transformed data follow the normal distribution, the original data are said to follow the lognormal distribution.

The verification of the normal distribution should begin with the use of the graphical methods described in Appendix K2. These methods include the histogram, box plot, and the probability plot. As described in Appendix K2, these plots provide a good understanding of whether the data distribution is symmetric and whether there are any potential outliers that need further investigation. If the graphical plots show that the data distribution is non-symmetric, one should prepare the same plots using log-transformed data.

Next, preliminary impressions based on a visual review of the data plots should be confirmed with a formal statistical test. The Shapiro-Wilk W test is recommended in several EPA guidance documents[13] and many statistical texts[14]. Tests such as the Shapiro-Wilk W test are called "Goodness-of-Fit" tests because they test how well a particular distribution fits the data. Basically, this test utilizes the linearity of the normal probability plot to produce test statistic called the *W* statistic. The more linear the normal probability plot, the higher the *W* statistic, and the greater the confidence that the data distribution is normal. Statistical packages can be used for determining if the probability of getting a *W* statistic in repetitive sampling lower than that calculated. If this probability is small enough (typically less than 0.05), one would conclude that the assumption of a normal distribution is not reasonable. This probability is called the significance probability and is denoted by the letter *p*. Thus, if the *p* value for the test is less than 0.05, one may conclude that the normal distribution is not a reasonable choice for the data being analyzed. The smaller the value of *p*, the greater is the confidence that the data distribution is non-normal. On the other hand, if the *p* value is higher than 0.05, one would conclude that the assumption of a normal distribution cannot be rejected.

[13] USEPA. 2006. *Data Quality Assessment: Statistical Methods for Practitioners*. EPA QA/G-9S. Office of Environmental Information, Washington, DC.
[14] Gibbons, Robert D. 1994. *Statistical Methods for Groundwater Monitoring*. John Wiley & Sons, Inc., New York.

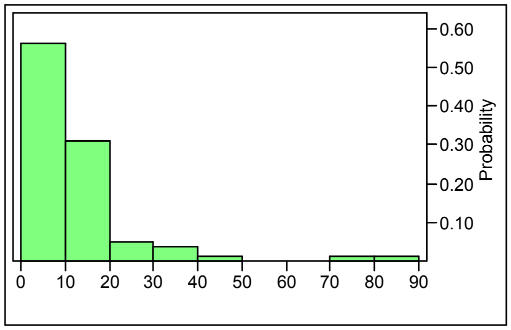
Example K4-2

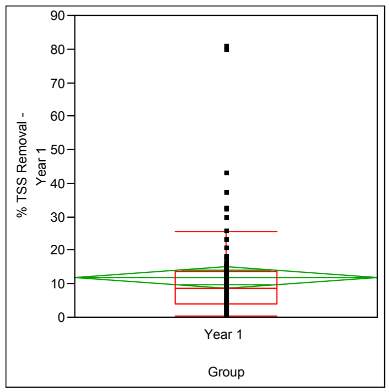
The same example that was used in Appendix K2 (Example K2-1) will be used here to build on the results of the graphical methods presented in Appendix K2. For ease of reference, the example and the data plots (histograms, box plots, and normal probability plots) are repeated here (see Figures K4-3). As was discussed in Appendix K2, these plots suggest that the data distribution is non-symmetric (specifically, right-skewed) and hence, the assumption of a normal distribution may not be valid. At the same time, the normal probability plot of log-transformed values showed a reasonable linear fit suggesting that the log-transformed values may follow a normal distribution (which also means that the original values may follow a lognormal distribution).

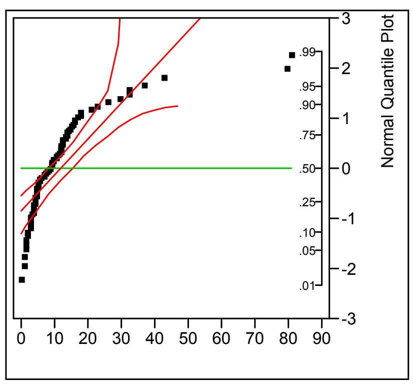
The formal Shapiro-Wilk W test is applied to confirm preliminary impressions. The JMP software will be used to perform this test. Figure K4-4 shows the relevant JMP output. Under the label "Shapiro-Wilk W Test," the JMP output lists the *W* statistic and the significance probability, *p*, that is shown under the label "Prob<W." If this probability is less than 0.05, one would conclude that the assumption of normal distribution is not reasonable. For the illustrative example, the *W* statistic for this probability is less than 0.0001, which suggests that the data are highly non-normal. This finding reinforces the impressions formed based on a visual review of the data plots. Note that for Caltrans studies, the 90 percent confidence level should be used.

Since the histogram and the box plot suggest that the data are right-skewed, it is appropriate to examine whether a logarithmic transformation of the data may yield a symmetric distribution that could be assumed to be normal. In Figure K4-4, the results of the Shapiro-Wilk W test are also shown for log-transformed values. The *W* statistic now is 0.97 (in contrast to being 0.64 for the original data values; higher values suggest a better fit to a straight line and greater justification for the assumed probability distribution) and the significance level, *p*, is 0.11, suggesting that the assumption of a normal distribution for the log-transformed data cannot be rejected.

Percent TSS Removal - Year 1







Log-transformed Percent TSS Removal - Year 1

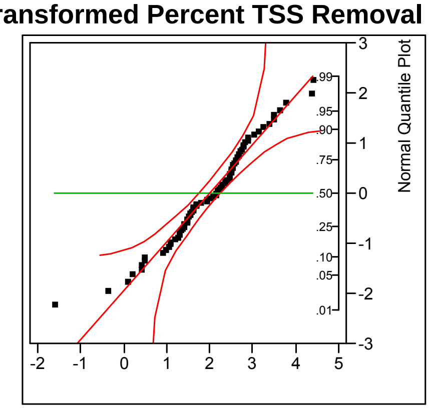


Figure K4-3 Histograms, Box Plots, and Normal Probability Plots for Example K4-2

Percent TSS Removal - Year 1

Fitted Normal
Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	μ	11.84625	8.7517622	14.940738
Dispersion	σ	13.905367	12.034439	16.470526

Goodness-of-Fit Test
Shapiro-Wilk W Test

W	Prob<W
0.642457	<.0001

Log-transformed Percent TSS Removal - Year 1

Fitted Normal
Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	μ	1.9990029	1.7706293	2.2273764
Dispersion	σ	1.0262177	0.888143	1.2155268

Goodness-of-Fit Test
Shapiro-Wilk W Test

W	Prob<W
0.974228	0.1057

Figure K4-4 Shapiro-Wilk W Test Results for Example K4-2

K4.4 Verification of Equal Variance Between Groups

In Appendix K2, it was noted that some of the study questions would be related to evaluating difference among different groups. Common statistical methods for answering these questions are drawn from the category of parametric tests. As noted above, one important assumption made in parametric tests is that each data group is normally distributed. An additional assumption made in these tests is that the data variability (expressed in terms of the variance) of the different data groups is the same.

Tests for verifying this assumption fall under the category “Homogeneity of Variance” tests. A common test in this category is the Levene’s test. The JMP software package includes five different tests for checking homogeneity of variance, one of which is the Levene’s test. Although the results of the five tests often are consistent (i.e., they lead to the same conclusion), that is not always the case. To simplify the analysis, it is recommended that only the results of the Levene’s test be used to draw conclusions regarding homogeneity of variance.

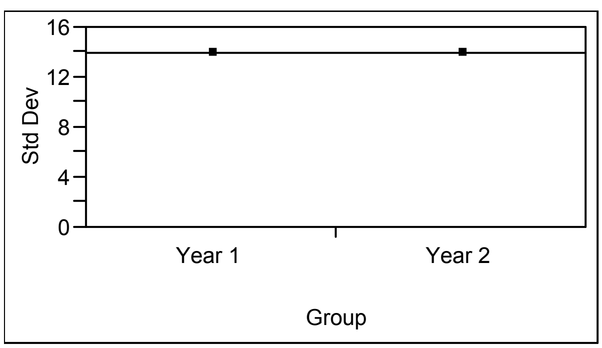
The JMP software summarizes the results of the Levene's test (and other tests) in terms of the significance probability, *p*. As in the case of the Shapiro-Wilk W test, this probability is compared to some threshold value (typically 0.05). If *p* is less than 0.05, the variances are considered to be unequal. If *p* is equal to or greater than 0.05, the assumption of equal variances cannot be rejected.

If one concludes that the variances are unequal, alternative methods of statistical analysis should be used. Appendix K6 describes a method called Welch ANOVA that could be used if the data sets can be assumed to be normally distributed, but have unequal variances.

Example K4-3

Example K2-1, previously used in Appendix K2, will be used to compare the BMP performance for Years 1 and 2. The data plots and summary statistics for the two years were shown previously in Appendix K2. The JMP software package was used to apply the Levene's test to check whether the variances of the data for the two years are the same. The results are shown in Figure K4-5. The Levene's test results are highlighted. The significance probability is listed as approximately 0.78. Based on this probability, one would conclude that the assumption of equal variances cannot be rejected.

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Year 1	80	13.90537	8.240125	7.798750
Year 2	80	13.97970	8.735031	8.253750

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.0003	1	158	0.9854
Brown-Forsythe	0.0589	1	158	0.8085
Levene	0.0807	1	158	0.7767
Bartlett	0.0022	1	.	0.9623
F Test 2-sided	1.0107	79	79	0.9623

Figure K4-5 Levene's Test Results for Example K4-3

Appendix K5 How to Estimate Probabilities Using Data for a Single Variable

K5.1 Purpose and Organization

The purpose of this appendix is to present methods to analyze data for a single variable (e.g., effluent concentration of a specified constituent of concern) to address the following types of study questions:

- How often would the effluent concentration exceed a specified legal limit?
- What is the estimated effluent concentration that would be exceeded no more than a specified percentage of time?
- What is an estimate of the mean concentration with a specified confidence level?

The methods presented are organized by assumptions that could be made about the probability distribution of the sample data for the variable of interest. Methods presented in Appendix K4 can be used to assess whether it is reasonable to assume a normal distribution for original or log-transformed data.

To address the first two study questions posed above, one needs to work with a probability distribution for the data. Two commonly used probability distributions – normal and lognormal – will be considered. The key features of each distribution are described and displayed graphically, and the use of each distribution to estimate probabilities of interest is illustrated with an example. Methods are also presented if neither normal nor lognormal distribution can be assumed for given data or the data contains nondetects.

To address the third study question posed above, the basic concepts are presented and the use of a software program developed by the USEPA is described.

K5.2 Use of Normal Distribution to Estimate Probabilities

The graphical methods described in Appendix K2 can be used to develop preliminary conclusions regarding whether the data distribution is symmetric or skewed and whether the normal probability plot fits close to a straight line. If these preliminary conclusions suggest that the data distribution appears to be symmetric and the normal probability plot shows a reasonable fit to a straight line, one should use the formal goodness-of-fit test (i.e., the Shapiro-Wilk W test) to check whether the assumption of a normal distribution is reasonable. If the Shapiro-Wilk W test verifies the reasonableness of the normality assumption, one can use the normal distribution to assess various probabilities of interest for the variable being studied.

Key features of a normal distribution and an example to illustrate its use to address study questions of interest are provided below.

The normal distribution is a bell-shaped, symmetric distribution characterized by two parameters – the mean (μ) and variance (σ^2) (or standard deviation, which is the square root of variance). These two parameters can be estimated by the sample mean (commonly denoted by $\bar{x}$) and sample variance (commonly denoted by s^2). The use of the statistical software package JMP to develop numerical data summaries was described in Appendix K2. For simple statistical tasks (such as estimating sample mean and sample variance), one can also use the statistical functions built in Microsoft Excel. The Excel functions for calculating the sample mean and sample variance are AVERAGE and VAR, respectively. The Excel function STDEV calculates the sample standard deviation, which is the square root of the sample variance.

The normal distribution of a variable, *X*, (e.g., zinc concentration in a BMP effluent) is mathematically characterized in terms of its *probability density function, f(x),* which is a plot of the relative frequency against different values of the variable. This function covers the range from minus infinity to plus infinity and is fully defined by the two parameters, namely, the mean and variance. The probability density function may be thought of as a continuous curve fitted to a histogram. Figure K5-1 shows typical normal probability density functions for two different combinations of mean and variance. The height (ordinate) of the curve, *f(x)* at a value *x*, is the probability that the variable *X* would be between *x* and *x+ dx*. Extending this concept to a range of *x* values, the probability that the variable *X* would be between x_1 and x_2 is the area under the curve between the limits of x_1 to x_2. Figure K5-1 illustrates this concept by shading the area under the curve that would correspond to the probability of being between x_1 and x_2. The area under the entire curve, from minus infinity to plus infinity, is one.

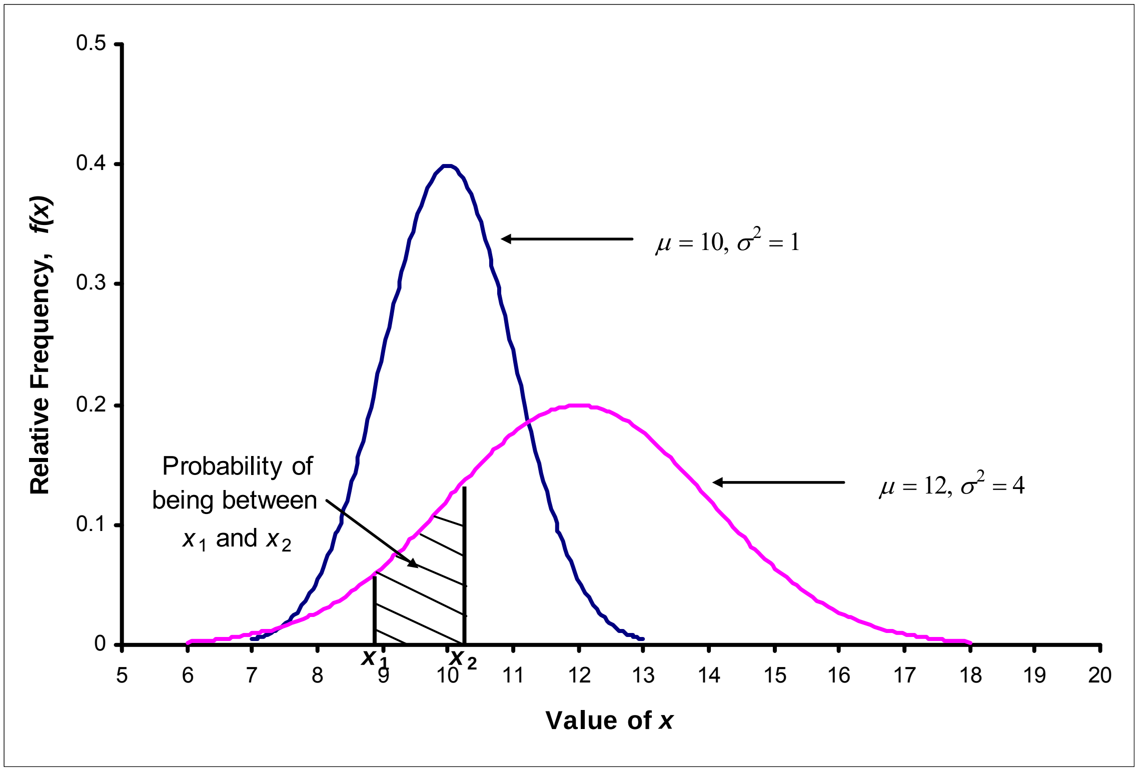


Figure K5-1 Two Normal Distributions: N(10, 1) and N(12, 4)

The normal probability density function is centered on, and symmetric around, its mean value. It has a single mode (peak) also at the mean value, and the median (50 percent probability) is also the same as the mean.

Although the complete range of a normal distribution includes negative values, a variable that only takes on positive values can still be assumed to be normally distributed if the area (probability) of the normal probability density function below 0 is negligible.

Example K5-1

Assume that zinc concentrations were measured in the BMP effluent over a period of two years. Table K5.1 shows the data. One wants to: (1) assess the probability that the zinc effluent concentration exceeds a limit of 18 mg/L, (2) assess the probability that zinc effluent concentration is between 10 and 15 mg/L, and (3) find the zinc effluent concentration that would be exceeded no more than 10 percent of the time. JMP will be used to prepare certain graphical plots and Excel will be used to estimate the probabilities of interest (JMP could also be used to estimate these probabilities).

Figure K5-2 shows the histogram, box plot, and normal probability plot for the example data. These plots suggest that the data distribution is symmetric and no outliers appear to be present. The normal probability plot shows that the data points fit reasonably well on a straight line. Based on these observations, a preliminary conclusion can be drawn that the assumption of a normal distribution for this data may be reasonable and should be formally checked. The Shapiro-Wilk W test was applied using JMP and the results are shown in Figure K5-2. The significance probability, *p*, is 1.0, well above the threshold of 0.05, verifying the assumption of a normal distribution is not unreasonable for this example data.

Next, one estimates the two parameters of the normal distribution, namely, the mean and standard deviation. Using Excel functions, the estimated values of the mean and standard deviation are 10.5 and 4.36, respectively.

One should then verify that the probability of getting negative values is negligible. In Excel, the statistical function NORMDIST(*x*, mean, standard deviation, true) returns the (cumulative) probability of being less than or equal to *x* from a normal distribution with the specified mean and standard deviation. For the illustrative example, this probability is found from NORMDIST(0, 10.5, 4.36, true). This value is 0.0078, which is negligible. Hence, the use of a normal distribution is reasonable for the example even though zinc concentration can only assume positive values.

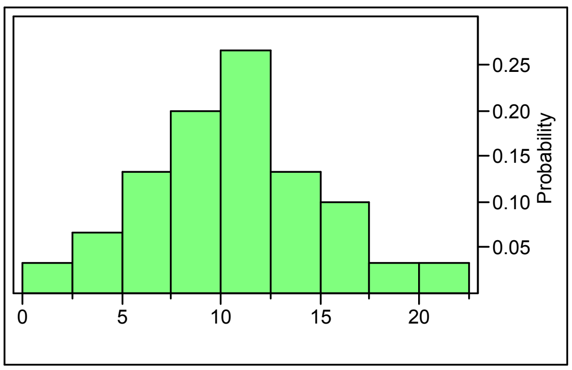
Next, one assesses the probability that zinc concentration exceeds 18 mg/L. Note that the Excel function NORMDIST returns the (cumulative) probability of being less than or equal to a specified value. The sum of the (cumulative) probability of being less than or equal to a specified value and the probability of exceeding the same value would be one. Hence, the probability of exceeding the specified value can be calculated by subtracting the cumulative probability from 1. For this example, the probability of interest is 1 - NORMDIST(18, 10.5, 4.36, true). This probability is found to be 0.044.

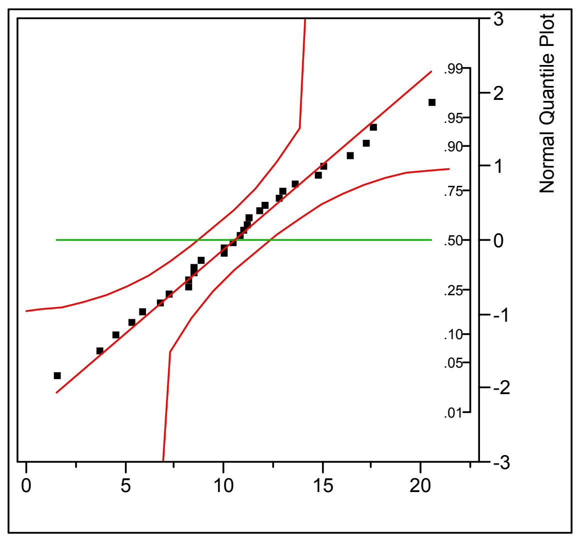
Next, to estimate the probability that zinc concentration is between the limits of 10 and 15 mg/L, one uses the NORMDIST function twice – once at the value of 10 and once at the value of 15. The difference between these two cumulative probabilities is the probability of being within the range of 10 to 15 mg/L. Thus, the probability of interest is (NORMDIST(15, 10.5, 4.36, true) - NORMDIST(10, 10.5, 4.36, true)) = 0.40.

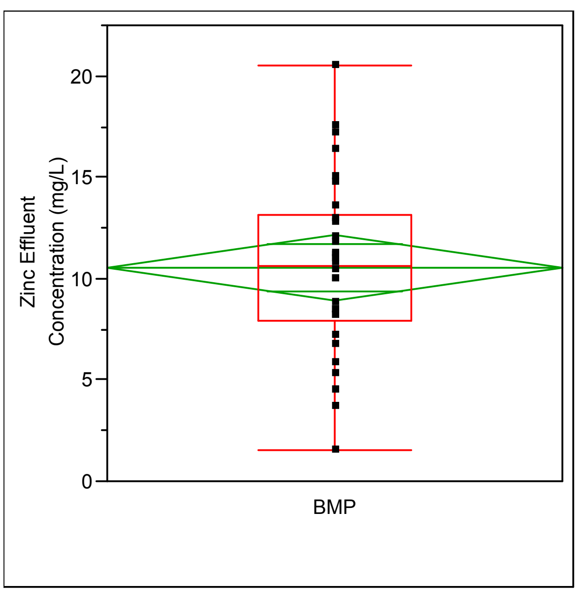
Finally, to find the zinc effluent concentration that would be exceeded no more than 10 percent of the time, one uses the Excel statistical function NORMINV(cumulative probability, mean, standard deviation). This function is the inverse of the function NORMDIST; it returns the value of the variable that has the specified cumulative probability given the specified mean and standard deviation of the normal variable. To find the value that would be exceeded no more than a certain proportion of the time, one must first find the corresponding cumulative probability, which would be (1 - the specified proportion of exceeding) and then use the function NORMINV. For this example, one wants to find the zinc effluent concentration that would be exceeded no more than 10 percent of the time. The corresponding cumulative probability is (1 - 0.1) = 0.9. The Excel function NORMINV(0.9, 10.5, 4.36) returns the value of 16.1. Thus, the zinc concentration of 16.1 mg/L would be exceeded no more than 10 percent of the time.

Table K5.1 Example K5-1 – Zinc Effluent Concentrations in mg/L Measured Over a Period of 2 Years

1.52	8.47	12.09
3.71	8.86	12.81
4.49	9.99	12.98
5.35	10.01	13.59
5.89	10.47	14.72
6.78	10.81	15.07
7.18	10.94	16.37
8.21	11.14	17.22
8.23	11.24	17.54
8.43	11.82	20.48







Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.992706	0.9987

Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.

Figure K5-2 Histogram, Box Plot, Normal Probability Plot, and Shapiro Wilk W Test Results of Example K5-1, Zinc Effluent Concentration (mg/L)

K5.3 Use of Lognormal Distribution to Estimate Probabilities

If the histogram and box plot show that data distribution is not symmetric, but is right-skewed, this would suggest that the assumption of a normal distribution might not be reasonable. This would be further reflected in the normal probability plot that shows that the data points do not fit well on a straight line. In this case, a lognormal distribution may provide a better fit to the data. For many environmental variables, the data distribution is right-skewed, and hence the assumption of a lognormal distribution, rather than the symmetric normal distribution, might be more appropriate.

If the variable X is lognormally distributed, the variable Y, which is the natural logarithm of X ($Y = ln(X)$), would be normally distributed. Therefore, the methods described in the preceding section on the normal distribution can be directly used on Y. Thus, the mean (μ_y) and variance (σ_y^2) of Y would fully define the normal distribution of Y, which, in turn, will fully define the lognormal distribution of X. Note that the mean of Y is also the median of Y, which can be back-transformed into the median of X (i.e., median of X = exponentiate of (mean of Y)). An alternative way of characterizing a lognormal distribution is to specify the median of X and the variance of Y.

Figure K5-3 shows some typical lognormal distributions of X for different combinations of mean and variance of Y. Note that when the variance of Y is relatively small (less than 0.25), the lognormal distribution becomes more symmetric and resembles a normal distribution.

Example K5-2

Consider the zinc effluent concentrations shown in Table K5.2. Figure K5-4 shows the histogram, box plot, and normal probability plot. The histogram and the box plot suggest a non-symmetric (right-skewed) distribution and the normal probability plot shows a nonlinear pattern. Based on these observations, one would conclude that the data may not be normally distributed. This is confirmed through the Shapiro-Wilk W test results also shown in Figure K5-4. The significance probability, p, for the Shapiro-Wilk W test is 0.0002, well below the threshold of 0.05, which leads to the conclusion that the data do not fit a normal distribution.

Given the right-skewed data distribution, it would be appropriate to explore the possibility of fitting a lognormal distribution. Figure K5-5 shows the histogram, box plot, normal probability plot, and results of the Shapiro-Wilk W test using the log-transformed data. All results suggest that the assumption of a lognormal distribution would be appropriate for this data. Note that, unlike a normal distribution, a lognormal distribution can only take on positive values.

The study questions are similar to those previously posed. For this example, one wants to: (1) assess the probability that zinc effluent concentration exceeds a limit of 5 mg/L, (2) assess the probability that zinc effluent concentration is between 3 and 4 mg/L, and (3) find the zinc effluent concentration that would be exceeded no more than 10 percent of the time.

The normal distribution of log-transformed concentrations will be used to address these questions. The mean and standard deviation of *ln*(zinc concentration) are calculated to be 0.138 and 1.06, respectively. The probability that zinc concentration exceeds the limit of 5 mg/L is the same as the probability that *ln*(zinc concentration) exceeds *ln* of 5. Thus, the probability of interest is given by (1- NORMDIST(LN(5), 0.138, 1.06, true)), which is equal to 0.082.

Next, the probability that zinc concentration is between 3 and 4 mg/L is given by (NORMDIST(LN(4), 0.138, 1.06, true) – NORMDIST(LN(3),0.138, 1.06, true)), which is equal to 0.063.

Finally, the zinc concentration that would be exceeded no more than 10 percent of the time is found as EXP(NORMINV((1-0.1), 0.138, 1.06)), which is equal to 4.46 mg/L.

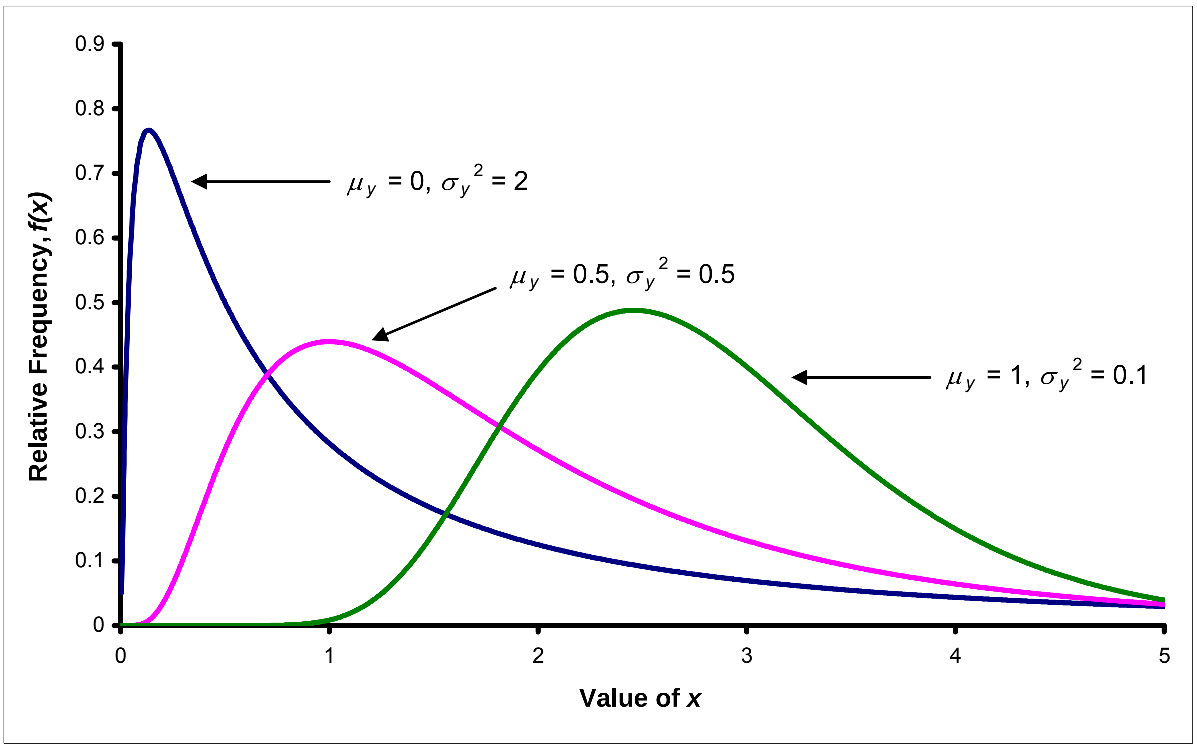
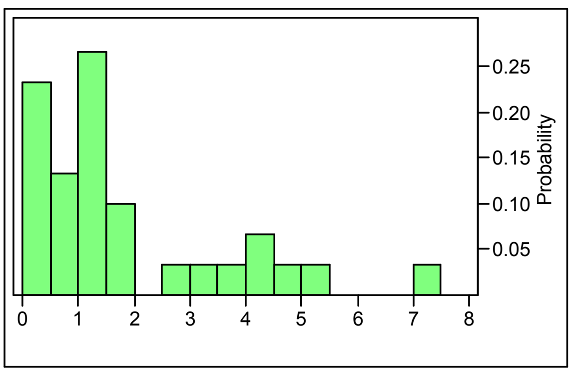
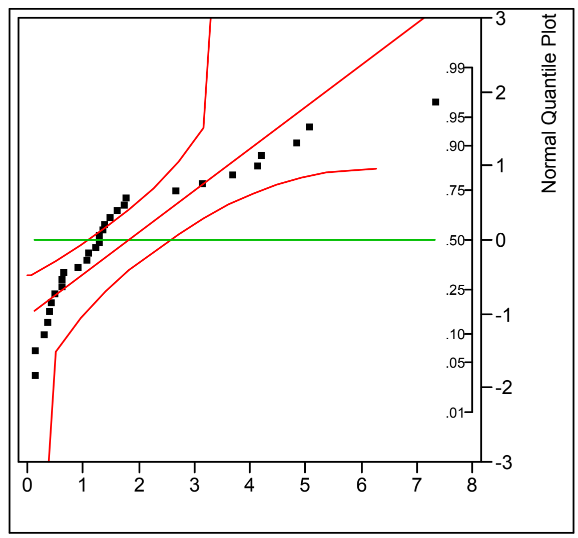


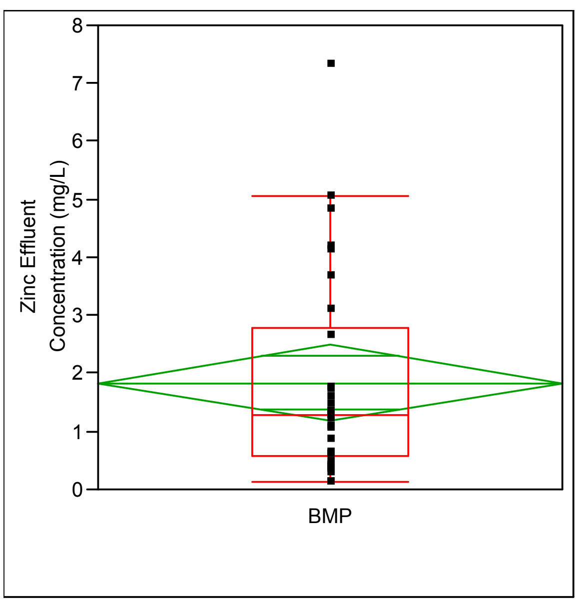
Figure K5-3 Three Lognormal Distributions: LN(0, 2), LN(0.5, 0.5), and LN(1, 0.1)

Table K5.2 Example K5-2 – Zinc Effluent Concentrations in mg/L Measured Over a Period of 2 Years

1.27	3.12	1.75
1.36	4.14	0.12
5.05	0.12	7.34
0.41	3.68	1.48
1.1	1.06	0.48
0.37	1.34	1.21
0.6	1.61	1.27
4.18	0.88	0.63
0.61	0.29	2.66
1.73	0.36	4.84







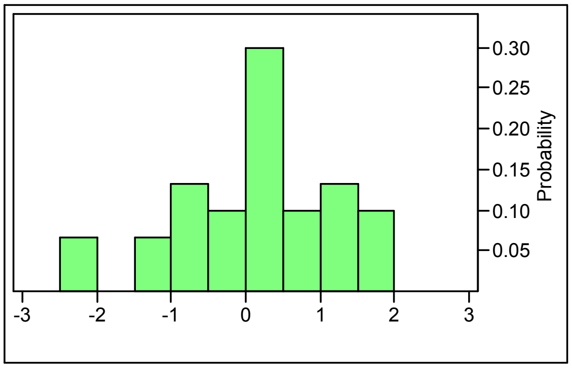
Goodness-of-Fit Test

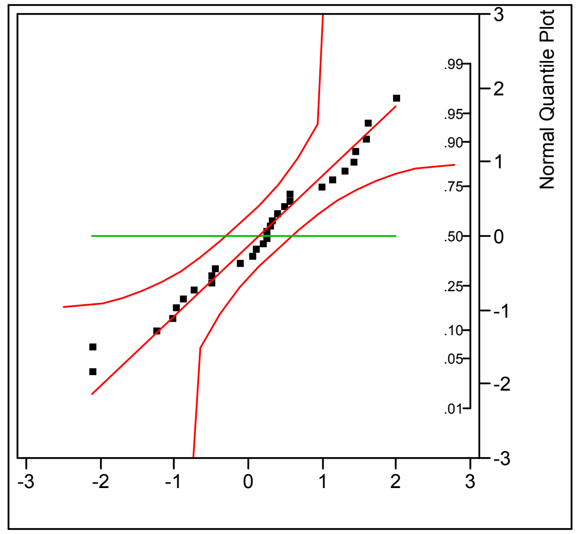
Shapiro-Wilk W Test

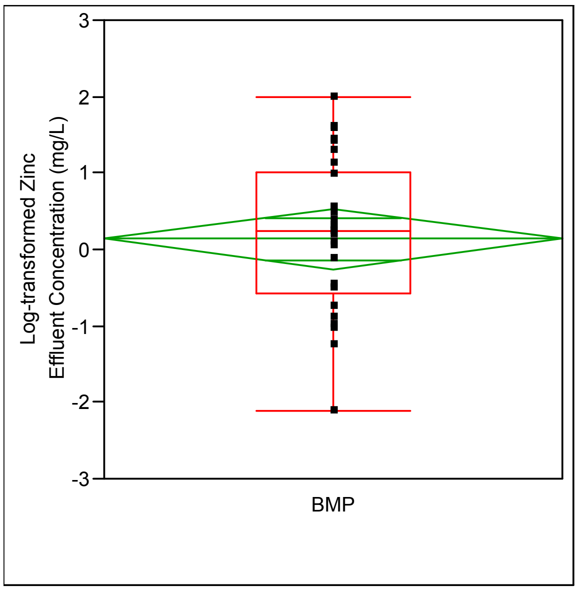
W	Prob<W
0.820594	0.0002

Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.

Figure K5-4 Histogram, Box Plot, Normal Probability Plot, and Shapiro Wilk W Test Results of Example K5-2, Zinc Effluent Concentration (mg/L)







Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.968429	0.4971

Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.

Figure K5-5 Histogram, Box Plot, Normal Probability Plot, and Shapiro Wilk W Test Results of Example K5-2, Log-transformed Zinc Effluent Concentration (mg/L)

K5.4 If Neither Normal Nor Lognormal Distribution Can Be Assumed

If neither a normal nor a lognormal distribution can be assumed for a given data set, different methods of analysis would be needed. The recommended method is described below.

The recommended method is to use empirical estimates of the proportion of data below (or above) a specified value. These estimates do not assume a specific data distribution. In Excel, the statistical function PERCENTRANK(data array, *x*) can be used to find an empirical estimate of the proportion of data values that would be less than or equal to the specified value, *x*. This proportion then can be interpreted as the cumulative probability of being less than or equal to *x*. One limitation of this approach is that *x* cannot be greater than the maximum data value. The probability of exceeding the maximum data value is calculated to be 0. For a small sample size, the estimated probability of exceeding a relatively high value may not be reliable.

To obtain an empirical estimate of the value *x* that is exceeded no more than a specified proportion of the time, one can use the Excel function PERCENTILE(data array, cumulative proportion). For example, to find the *x* value that is exceeded no more than 10 percent of the time, one would set the cumulative proportion to (1 – 0.1) = 0.9.

Example K5-3

Example K5-2 from the preceding section will be used again. However, this time, a lognormal distribution will not be assumed. Instead, the empirical estimation approach will be used.

To estimate the probability that zinc effluent concentration does not exceed the limit of 5 mg/L, one can use the Excel function PERCENTRANK(data array, 5). The result is 0.957, whereas the same estimate from lognormal distribution is 0.918.

To find the probability that zinc concentration is between 3 and 4 mg/L, one can use the Excel functions PERCENTRANK(data array, 3) and PERCENTRANK(data array, 4) and find the difference between the two proportions. The result is 0.067, whereas the same estimate from lognormal distribution is 0.063.

To find the zinc effluent concentration that would be exceeded no more than 10 percent of the time, one can use the Excel function PERCENTILE(data array, 0.9). The result is 4.25 mg/L, whereas the same estimate from lognormal distribution is 4.46 mg/L.

K5.5 If Data Contains Nondetects

If the data contains nondetects, the recommended methods described in Appendix K3 may be used. If the robust Regression on Order Statistics (ROS) method is used, it will generate replacement values for nondetects. These replacement values can be combined with the detect values and the combined data set can be used as if no censoring occurred. Then, the methods described in the preceding sections will be applicable to the combined data set. If the percentile method is used and the percentage of detects is greater than the percentile of interest, one can estimate this percentile without making any assumptions about the nondetects. For example, one is interested in estimating the 80^{th} percentile and the percentage of detects is 90 percent, one can estimate the 80^{th} percentile directly from the data without making any assumptions about the nondetects.

K5.6 Estimation of Mean with Specified Confidence Level

For health risk assessment, an estimate of the mean with 95 percent upper confidence limit (UCL) is often required. This UCL estimate is commonly denoted as UCL95. However, note that for Caltrans studies, the 90 percent confidence level should be used. The USEPA has developed a software program called ProUCL that could be downloaded from the following site: www.epa.gov/nerlesd1/tsc/software.htm. Extensive research has gone into the development of ProUCL and it is currently the best option to estimate UCL95. There is detailed documentation on the methodology used in ProUCL, which can also be downloaded from the same site.

ProUCL automatically evaluates a large number of methods and distributions to estimate UCL95 and then recommends one preferred method and the resulting UCL95. At present time, ProUCL does not address the issue of nondetects. However, an updated version is expected to be available in the near future that will properly handle nondetects.

Example K5-4

Example K5-2 will be used again to estimate UCL95 using the ProUCL software. The ProUCL output is displayed in Figure K5-6. The recommended method for estimating UCL95 is assuming gamma distribution (Approximate Gamma UCL). The UCL95 using this method is 2.51 mg/L. In this example the mean zinc concentration is 1.84 mg/L and the 95 percent upper confidence concentration is 2.51 mg/L.. Note that for Caltrans studies, the 90 percent confidence level should be used.

Data File		Variable:	Zinc Effluent Concentration (mg/L)
Raw Statistics		**Normal Distribution Test**	
Number of Valid Samples	30	Shapiro-Wilk Test Statisitic	0.820595
Number of Unique Samples	28	Shapiro-Wilk 5% Critical Value	0.927
Minimum	0.12	Data not normal at 5% significance level	
Maximum	7.34		
Mean	1.835333	**95% UCL (Assuming Normal Distribution)**	
Median	1.27	Student's-t UCL	2.384563
Standard Deviation	1.770472		
Variance	3.134571	**Gamma Distribution Test**	
Coefficient of Variation	0.96466	A-D Test Statistic	0.392582
Skewness	1.515218	A-D 5% Critical Value	0.770371
		K-S Test Statistic	0.132146
Gamma Statistics		K-S 5% Critical Value	0.164002
k hat	1.205194	Data follow gamma distribution	
k star (bias corrected)	1.106897	at 5% significance level	
Theta hat	1.522853		
Theta star	1.658089	**95% UCLs (Assuming Gamma Distribution)**	
nu hat	72.31165	Approximate Gamma UCL	2.505142
nu star	66.41382	Adjusted Gamma UCL	2.551113
Approx.Chi Square Value (.05)	48.65652		
Adjusted Level of Significance	0.041	**Lognormal Distribution Test**	
Adjusted Chi Square Value	47.77974	Shapiro-Wilk Test Statisitic	0.965343
		Shapiro-Wilk 5% Critical Value	0.927
Log-transformed Statistics		Data are lognormal at 5% significance level	
Minimum of log data	-2.12026		
Maximum of log data	1.993339	**95% UCLs (Assuming Lognormal Distribution)**	
Mean of log data	0.138109	95% H-UCL	3.29045
Standard Deviation of log data	1.058392	95% Chebyshev (MVUE) UCL	3.869787
Variance of log data	1.120193	97.5% Chebyshev (MVUE) UCL	4.69825
		99% Chebyshev (MVUE) UCL	6.325604
		95% Non-parametric UCLs	
		CLT UCL	2.36702
		Adj-CLT UCL (Adjusted for skewness)	2.462568
		Mod-t UCL (Adjusted for skewness)	2.399467
		Jackknife UCL	2.384563
		Standard Bootstrap UCL	2.364356
		Bootstrap-t UCL	2.503655
RECOMMENDATION		Hall's Bootstrap UCL	2.521498
Data follow gamma distribution (0.05)		Percentile Bootstrap UCL	2.377667
		BCA Bootstrap UCL	2.478333
Use Approximate Gamma UCL		95% Chebyshev (Mean, Sd) UCL	3.244315
		97.5% Chebyshev (Mean, Sd) UCL	3.853982
		99% Chebyshev (Mean, Sd) UCL	5.051555

Figure K5-6 ProUCL (Version 3.0) Output for Data of Example K5-2

Appendix K6 How to Compare Two Independent Data Sets

K6.1 Purpose and Organization

The purpose of this appendix is to present statistical methods to compare two independent data sets and draw conclusions regarding whether observed differences in the two data sets are statistically significant. For example, BMP monitoring approaches, such as paired watershed monitoring, generate data that are representative of two independent populations of interest (e.g., water quality in control (undisturbed) and treatment (disturbed) watersheds). Similarly, studies to evaluate the effectiveness of two different BMPs generate data on two independent populations representing the effects of the two BMPs.

Typical study questions of interest in the analysis of two independent data sets are:

- In a paired watershed approach, how does one decide whether there is a significant increase in pollutant concentration in the disturbed watershed?
- How does one compare the effectiveness of two pilot BMPs at a given geographic location?

Since the statistical methods to address these and other similar study questions fall under the general category of *hypothesis testing*, the basic concepts of hypothesis testing will be discussed first. A decision flowchart is presented to guide the user in the selection of an appropriate statistical method, depending on the characteristics of each data set. The final sections in this appendix provide an overview of each method and illustrate its application with examples related to BMP studies.

K6.2 Basic Concepts of Hypothesis Testing

The statistical methods described in this appendix (as well as in Appendices 7 through 10) belong to a general category of statistical methods called hypothesis testing. Figure K6-1 provides a flowchart of the key steps in hypothesis testing. An overview of each step is provided below.

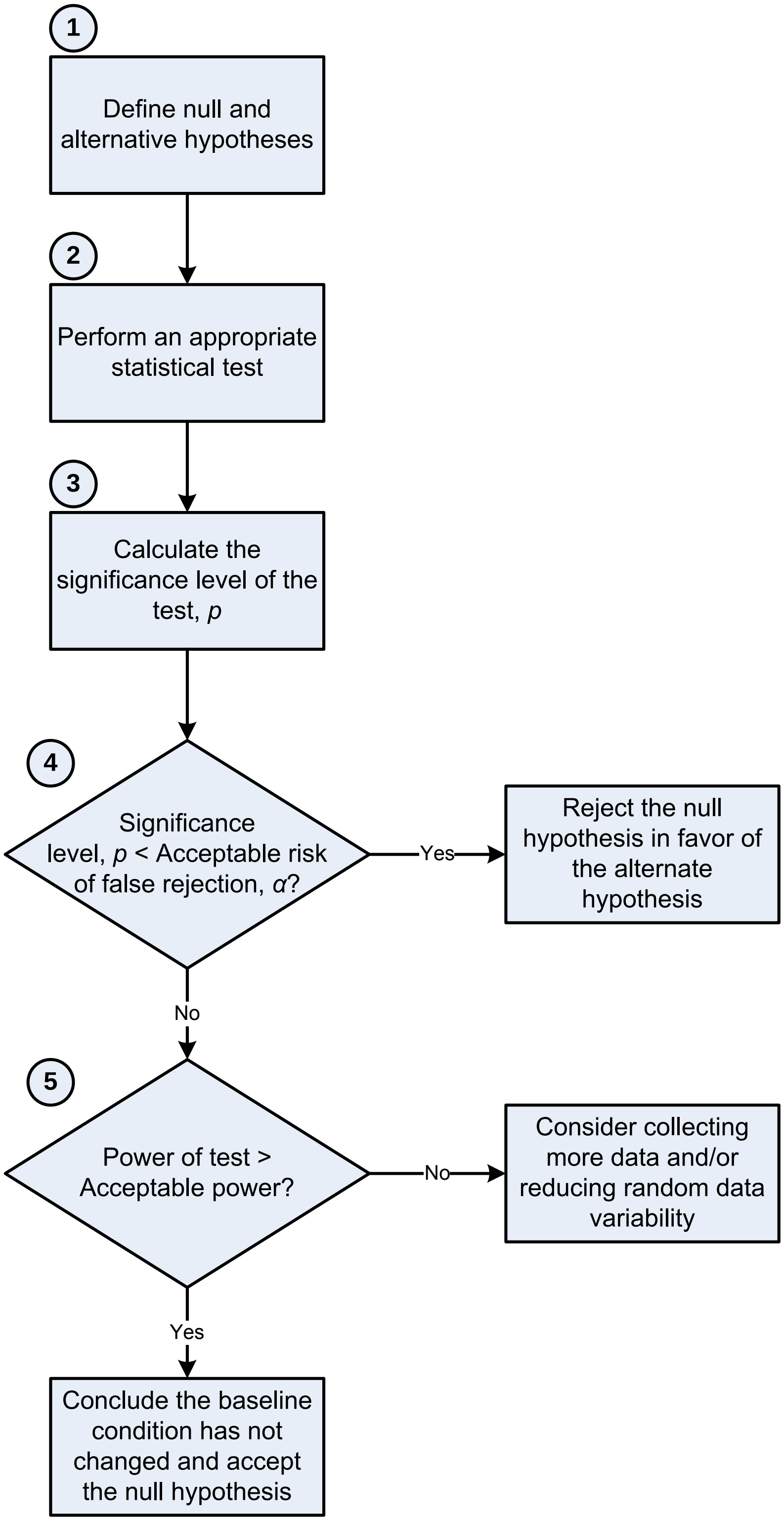


Figure K6-1 Flowchart of Key Steps in Hypothesis Testing

K6.2.1 Step 1. Define Null and Alternative Hypotheses

Hypothesis testing involves deciding whether a change from an assumed baseline condition has occurred. The baseline condition is the condition that is assumed to exist unless there is contrary evidence provided by the sample data. In the statistical literature, the baseline condition is called the *null hypothesis* and is denoted by H_0. The changed condition is called the *alternative hypothesis* and is denoted by H_A.

The following example will be used to illustrate the definition of null and alternative hypotheses. Assume that a paired watershed approach will be used to evaluate whether there is a significant increase in the mean pollutant concentration in a disturbed watershed relative to a matched undisturbed watershed. The assumed baseline condition will be that the average pollutant concentration in the disturbed watershed is no higher than that in the undisturbed watershed. If the sample data show strong contrary evidence, one can reject the assumed baseline condition and conclude that the average pollutant concentration in the disturbed watershed is higher than that in the undisturbed watershed.

Let μ_1 and μ_2 denote the true average pollutant concentrations in the disturbed and undisturbed watersheds, respectively. Then, the null and alternative hypotheses for this example can be defined as follows:

Null Hypothesis, H_0: $\mu_1 \leq \mu_2$

Alternative Hypothesis, H_A: $\mu_1 > \mu_2$

K6.2.2 Step 2. Perform an Appropriate Statistical Test

A flowchart of appropriate statistical tests for the comparison of two independent populations is presented in Section K6.3.

K6.2.3 Step 3. Calculate the Significance Level, *p*, of the Test

The significance level of a statistical test, denoted by p, is the probability of observing a change from the baseline condition at least as extreme as that found in the sample data by chance alone when the baseline condition, in fact, has not changed. The smaller the p, the greater the confidence that the observed change in the sample data is “real”; that is, the observed change reflects a true change from the baseline condition and is not simply because of random chance.

When a change from the baseline condition only in one direction is of interest, the significance level is the probability of observing a change from the baseline condition in the direction of interest that is greater than that found in the sample data by chance alone. This is called a one-tailed statistical test. For example, in a paired watershed study, one is interested in evaluating whether a pollutant concentration in the disturbed watershed is higher than that in the undisturbed watershed. This evaluation should be based on a one-tailed statistical test. That is, the significance level in this case is the probability of observing an increase in the pollutant concentration greater than that found in the sample data by chance alone. Conversely, if a change from the baseline condition in either direction is of interest, the significance level is the probability of observing a change from the baseline condition that is either higher or lower than that found in the sample data by chance alone. Equivalently, it is the probability of observing a change that is greater than the absolute value of the change found in the sample data by chance alone. This is called a two-tailed statistical test. For example, in evaluating changes in pH, both high and low levels of pH would be of concern. This evaluation should be based on a two-tailed test.

K6.2.4 Step 4. Compare the Significance Level to an Acceptable Risk of False Rejection

The acceptable risk of a false rejection (also called the probability of Type I error) is denoted by α. It is the probability of incorrectly concluding that the baseline condition has changed when, in fact, it has not changed. This type of an error could occur when, by chance alone, one gets an extreme sample that is not representative of the population as a whole. Typical values of α are 0.01, 0.05, and 0.1. These correspond to confidence levels of 0.99, 0.95, and 0.9, respectively, in reaching the correct conclusion of no change from the baseline condition. Note that for Caltrans studies, the 90 percent confidence level should be used.

If the significance level, p, is equal to or smaller than the acceptable risk of false rejection, α, one would conclude that the risk of a false rejection is sufficiently small. Therefore, one would reject the null hypothesis (H_0) in favor of the alternative hypothesis (H_A); that is, one would conclude that the baseline condition has changed. On the other hand, if p is higher than α, one would conclude that the risk of a false rejection is too high. Therefore, one would not reject the null hypothesis; that is, one would conclude that the sample data do not provide strong enough evidence to conclude that the baseline condition has changed.

Continuing with the watershed example, let $\overline{X_1}$ and $\overline{X_2}$ denote the sample mean concentrations in the disturbed and undisturbed watersheds, respectively. If the water quality in the disturbed watershed is deteriorated, one would expect that $\overline{X_1}$ would be greater than $\overline{X_2}$. Let d denote the difference between the two means; that is, $d = \overline{X_1} - \overline{X_2}$. Positive values of the difference, d, would suggest that the water quality in the disturbed watershed might have deteriorated. Since d is estimated based on sample means, which vary from one set of samples to another, one could, by chance alone, get a relatively high value of d for the actual sample set that has been collected. However, the higher the value of d, the greater would be the confidence that the observed difference between the two sample means is "real" (i.e., due to disturbance) and not by chance alone.

Since one is interested only in a potential increase in pollutant concentration in the disturbed watershed, this evaluation should be based on a one-tailed test. The significance level in this case is the probability of observing an increase in the pollutant concentration that is higher than that found in the sample data. If this significance level is smaller than the specified α, one would conclude that the average pollutant concentration in the disturbed watershed is higher than that in the undisturbed watershed. Otherwise, one would conclude that the disturbance does not seem to have an impact on water quality.

K6.2.5 Step 5. Evaluate the Power of the Test if the Null Hypothesis is Not Rejected

If the null hypothesis is not rejected, one must be confident that, had the baseline condition changed by some magnitude of concern, the statistical test would have detected this change. This confidence is called the power of the test. Specifically, it is the probability of detecting a change, Δ, from the baseline condition. The power achieved for a given sample size is compared to the acceptable level of the power, which is denoted by $(1 - \beta)$. The term β is called the probability of *false acceptance*, or the probability of Type II error. Typical values of the power $(1 - \beta)$ are 0.8, 0.9, and 0.95. Note that for Caltrans studies, the 90 percent confidence level should be used.

Procedures to calculate the power of specific statistical tests are described in a subsequent section of this appendix. If the null hypothesis is not rejected (i.e., $p > \alpha$) <u>and</u> the power of the test to detect a specified change Δ is equal to or greater than $(1 - \beta)$, one will have sufficient confidence to conclude that the baseline condition has not changed. On the other hand, if the null hypothesis is not rejected <u>and</u> the power of detecting a change of Δ is less than $(1 - \beta)$, one only will be able to say that the baseline condition does not appear to have changed; however, one would not have sufficiently high confidence in making that statement. To increase the power of the test, one should consider collecting more data and/or reducing random data variability.

K6.3 Decision Flowchart

The choice of an appropriate statistical method for comparing two independent data sets depends on whether any nondetect (ND) values are present and whether the assumptions of normality and equal variance are satisfied. Figure K6-2 shows a flowchart for the selection of an appropriate method for different situations regarding these assumptions.

K6.3.1   No Nondetects in Both Data Sets

If there are no NDs in both data sets, the possibility of assuming a normal or lognormal distribution can be explored (Appendix K4). If either the original or log-transformed data fit a normal distribution, one needs to further check whether the two data sets have equal variances (Appendix K4). If both the assumptions of a normal distribution (for the original or log-transformed data) and equality of variances are satisfied, the Student's *t*-test with equal variance is used to compare the means of the two data sets. If the assumption of a normal distribution (for original or log-transformed data) is satisfied, but the assumption of equal variances is not satisfied, the Student's *t*-test with unequal variances is used. If neither assumption is satisfied, a nonparametric method that does not assume any particular distribution is used. A recommended nonparametric test in this situation is the Wilcoxon Rank Sum (WRS) test.

K6.3.2   One or More Nondetects (but at Least One Detect) in Either Data Set

If there is only one reporting limit (RL) for nondetect data and there is at least one detect in one or both data sets, the WRS test is again recommended. If there are multiple reporting limits (for nondetect data), more complex methods are required to analyze the data properly. One simple, although approximate, method is to set all data points below the highest RL to a common lowest value (such as zero) and then use the procedures shown for the case of a single RL.

K6.3.3   No Detects in Both Data Sets

If there are no detects in both data sets, no statistical analysis is possible. Professional judgment informed by qualitative factors may be used to compare the two data sets and draw conclusions.

The remainder of this appendix provides an overview of the various statistical tests noted in Figure K6-2 and examples to illustrate their use.

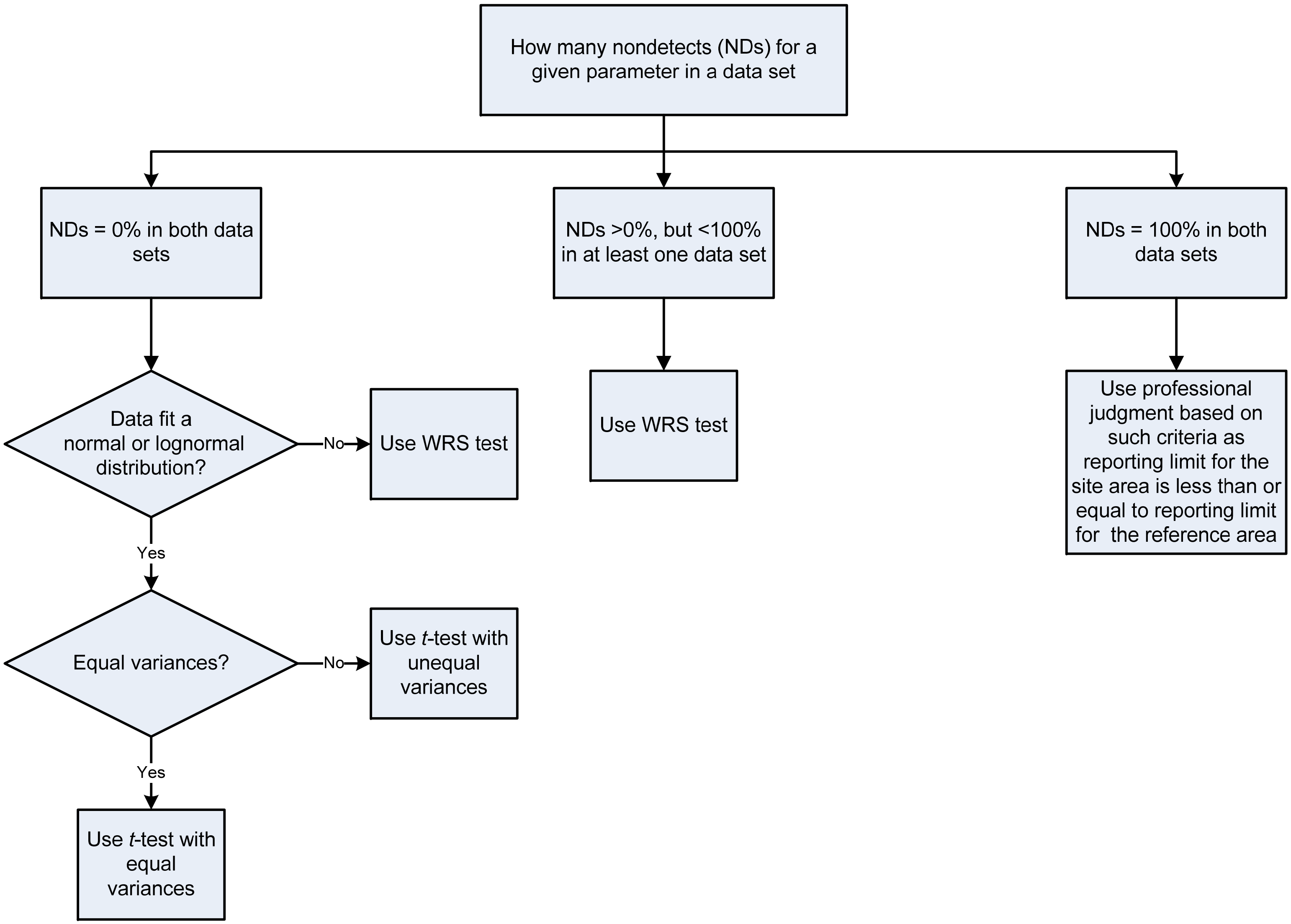


Figure K6-2 Select an Appropriate Statistical Method for Comparing Two Independent Data Sets

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K6.4 Description of Statistical Tests for Comparison of Two Independent Data Sets

The flowchart in Figure K6-2 identifies the following statistical tests:

- Student's *t*-test with equal variances
- Student's *t*-test with unequal variances
- Wilcoxon Rank Sum (WRS) test

The first two tests are parametric (i.e., they assume a particular probability distribution), while the third test is nonparametric (i.e., it assumes no specific distribution).

K6.4.1 Student's *t*-Test with Equal Variances

This test can be used to evaluate the difference between the means of two independent data sets when the sample data contain no nondetect measurements. The key assumptions made in this test are:

- Each data set follows a normal distribution; and
- The variances of the two data sets are equal.

The test is robust to moderate violations of the normality assumption, but not to large inequalities of variances. It is also not robust against outliers because sample means and standard deviations are sensitive to outliers. The normality assumption can be checked with graphical methods (histogram and normal probability plot described in Appendix K2) and a formal goodness-of-fit test (Shapiro-Wilk W test described in Appendix K4). The Levene's test described in Appendix K4 can be used to test the equality of variances. Methods described in Appendix K2 can be used to check whether the data contains potential outliers.

As was noted previously, if the null hypothesis is not rejected, the power of the test to detect a specified change from the baseline condition should be evaluated. For the Student's *t*-test with equal variance, the relatively simple procedure described in USEPA Guidance Document[15] is recommended. The procedure consists of finding the minimum sample size in each of the two data sets to satisfy the requirements of specified α, β, and Δ. The equation or the graphs provided in Appendix K1 can be used to find the minimum sample size. If the actual sample size in each data set is equal to or greater than the calculated minimum sample size, the test is considered to have adequate power.

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[15] USEPA. 2006. *Data Quality Assessment: Statistical Methods for Practitioners*. EPA QA/G-9S.

Example K6-1

In paired watershed monitoring study, lead concentration data shown in Table K6.1 was collected. The study question of interest is: Is the average lead concentration in the disturbed watershed higher than that in the matched undisturbed watershed? The steps of hypothesis testing shown in Figure K6-1 will be followed to answer this question.

The null and alternative hypotheses were defined as follows:

H_0: Mean of lead concentration in the disturbed watershed, $\mu_1 \leq$ Mean of lead concentration in the undisturbed watershed, μ_2 (i.e., the disturbance has not impacted the average lead concentration); and

H_A: $\mu_1 > \mu_2$ (i.e., the disturbance has increased the average lead concentration).

The application of the methods described in Appendix K2 revealed no outliers. JMP software was used to perform the Shapiro-Wilk W test to verify the assumption of normality of each data set. The Levene's test was used to verify the assumption of equal variances. The results of the two tests are shown in Figure K6-3. The relevant parts of the results are highlighted in green. The significance levels for the Shapiro-Wilk W and Levene's test are 0.9673 and 0.3397, respectively, as highlighted in Figure K6-3. Both are much higher than a typical threshold, α of 0.05. These results show that the assumptions of normality of each data set and equality of variances between the two data sets are reasonable. Therefore, the Student's *t*-test with equal variances is appropriate to use. The JMP software was used to perform this test. The results are shown in Figure K6-4.

As was described in Appendix K2, the horizontal lines inside the mean diamonds provide a simple visual method to assess whether the means of the two data sets are significantly different at 95 percent confidence level. Note that for Caltrans studies, the 90 percent confidence level should be used. Because the intervals defined by these horizontal lines in Figure K6-4 do not overlap, the means of the two data sets are significantly different at the 95 percent confidence level. This finding is next confirmed with the results of the formal test. The significance level, *p*, of the test is <0.0001, as highlighted in the figure. Because only increased lead concentrations in the disturbed watershed are of concern, this is a one-tailed test and the one-tailed *p* associated with this set-up is shown under the label "Prob > t." Assuming that the acceptable risk of false rejection, α, is set to 0.05, and since $p < \alpha$, one will reject the null hypothesis and accept the alternative hypothesis that the average lead concentration is higher in the disturbed watershed than in the undisturbed watershed.

Table K6.1 Lead Concentration Data for Example K6-1

Disturbed Watershed Lead Concentration (mg/L)

4.81	14.67	21.29
10.07	16.02	21.57
11.97	17.29	21.61
12.85	17.47	22.19
13.51	18.05	22.58
13.71	18.26	22.71
14.07	19.9	23.25
14.14	20.04	25.46
14.15	20.25	26.48
14.18	21.16	29.2

Undisturbed Watershed Lead Concentration (mg/L)

0.46	8.19	11.62
0.8	8.55	11.95
3.91	9.02	12.65
4.23	9.37	13.49
5.57	9.45	13.94
5.91	9.76	14.2
5.98	9.99	14.74
6.44	10.91	15.61
6.49	11.39	18.28
7.02	11.44	19.01

Distributions Group=Disturbed
Lead Concentration (mg/L)
Goodness-of-Fit Test
Shapiro-Wilk W Test

W	Prob<W
0.979079	0.8006

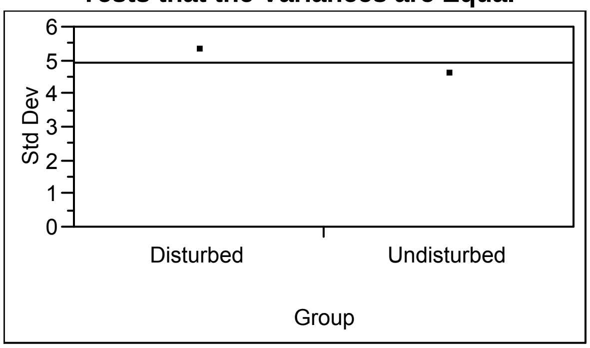
Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.

Distributions Group=Undisturbed
Lead Concentration (mg/L)
Goodness-of-Fit Test
Shapiro-Wilk W Test

W	Prob<W
0.987097	0.9673

Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.

Tests that the Variances are Equal

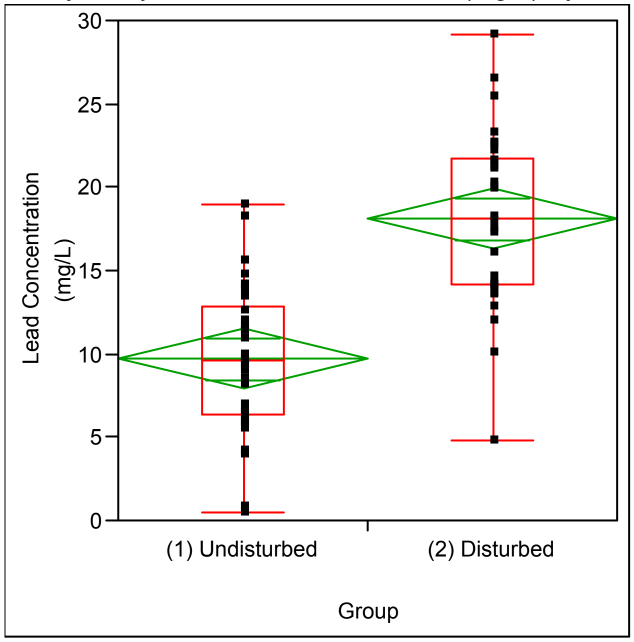


Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Disturbed	30	5.299161	4.299667	4.299667
Undisturbed	30	4.562705	3.586333	3.586333

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.6564	1	58	0.4211
Brown-Forsythe	0.9264	1	58	0.3398
Levene	0.9269	1	58	0.3397
Bartlett	0.6359	1	.	0.4252
F Test 2-sided	1.3489	29	29	0.4252

Figure K6-3 Shapiro-Wilk W Test and Levene's Test Results for Example K6-1

Oneway Analysis of Lead Concentration (mg/L) By Group



t Test

(2) Disturbed-(1) Undisturbed

Assuming equal variances

Difference	8.4180	t Ratio	6.593528
Std Err Dif	1.2767	DF	58
Upper CL Dif	10.9736	Prob > |t|	<.0001
Lower CL Dif	5.8624	Prob > t	<.0001
Confidence	0.95	Prob < t	1.0000

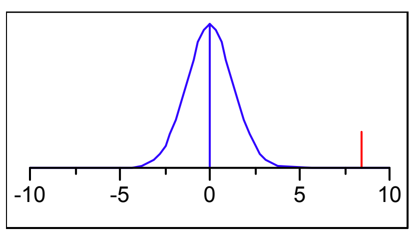


Figure K6-4 Student's t-Test with Equal Variances Result for Example K6-1

K6.4.2 Student's *t*-Test with Unequal Variances

This test can be used to evaluate the difference between the means of two independent populations when each population is normally distributed and the variances of the two populations are unequal. As with the previous test, the sample data should contain no nondetect measurements. In the JMP software, this test is labeled "t Test" "Assuming unequal variances." Example K6-2 considers this situation.

There is no simple method available to evaluate the power of the Student's *t*-test with unequal variances. Consultation with a statistician is recommended.

Example K6-2

Consider the lead concentration data shown in Table K6.2 for undisturbed and disturbed watersheds. The application of the methods described in Appendix K2 revealed no outliers. Figure K6-5 shows the results of applying the Shapiro-Wilk W test and the Levene's test. The relevant parts of the results are highlighted in green. Shapiro-Wilk W test shows that the significance level for this test is 0.3870 and hence each data set may be assumed to be normally distributed. The Levene's test shows that the significance level for this test is 0.0284 and hence variances of the two populations are considered to be significantly different. Therefore, the *t*-test assuming unequal variances should be used. The significance level, *p*, of the test is 0.7143, as highlighted in Figure K6-6. Because only increases in the lead concentration in the disturbed watershed are of concern, this is a one-tailed test and the one-tailed *p* associated with this set-up is shown under the label "Prob > t." Assuming that the acceptable risk of false rejection, α, is set to 0.05, and since $p > \alpha$, one cannot reject the null hypothesis. In other words, the disturbance does not appear to have a significant adverse impact on water quality. Note for Caltrans studies, the 90 percent confidence level should be used.

Table K6.2 Lead Concentration Data for Example K6-2

Disturbed Lead Concentration (mg/L)

4.85	7.48	11.25
5	8	11.44
5.53	8.4	12.74
5.68	9.12	12.94
6.22	9.44	13.1
6.23	9.52	13.13
6.28	9.89	13.88
6.61	10.64	13.97
7.41	10.64	16.23
7.47	10.97	17

Undisturbed Lead Concentration (mg/L)

1.9	7.67	12.37
2.14	7.75	12.4
2.61	8.36	13.71
3.28	9.81	13.99
3.92	10.76	15.16
5.72	10.81	15.83
6.35	11.11	15.84
6.43	11.32	18.14
6.78	11.67	21.62
7.16	12.15	24.6

Distributions Group=Disturbed
Lead Concentration (mg/L)
Goodness-of-Fit Test
Shapiro-Wilk W Test

W	Prob<W
0.954969	0.2292

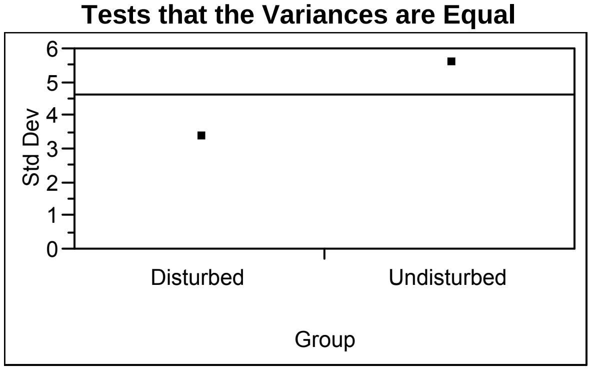
Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.

Distributions Group=Undisturbed
Lead Concentration (mg/L)
Goodness-of-Fit Test
Shapiro-Wilk W Test

W	Prob<W
0.963851	0.3870

Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.

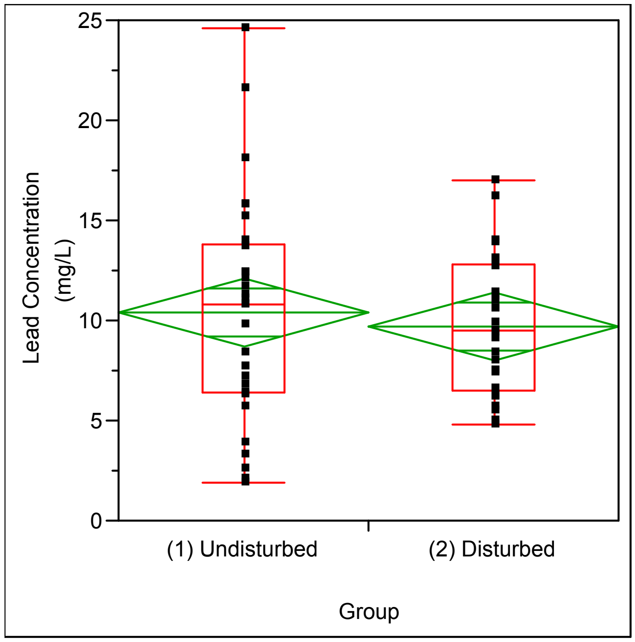
Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Disturbed	30	3.364448	2.799467	2.787333
Undisturbed	30	5.563758	4.361422	4.336000

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	5.0645	1	58	0.0282
Brown-Forsythe	4.7934	1	58	0.0326
Levene	5.0512	1	58	0.0284
Bartlett	6.9281	1	.	0.0085
F Test 2-sided	2.7347	29	29	0.0085

Figure K6-5 Shapiro-Wilk W Test and Levene's Test Results for Example K6-2



t Test

(2) Disturbed-(1) Undisturbed

Assuming unequal variances

Difference	-0.6767	t Ratio	-0.57003
Std Err Dif	1.1871	DF	47.70747
Upper CL Dif	1.7105	Prob > |t|	0.5713
Lower CL Dif	-3.0638	Prob > t	0.7143
Confidence	0.95	Prob < t	0.2857

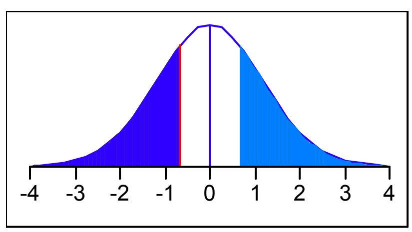


Figure K6-6 Student's *t*-Test with Unequal Variances Result for Example K6-2

K6.4.3 Wilcoxon Rank Sum (WRS) Test

This test can be used to evaluate the difference between the means of two independent populations under the following conditions:

(a) Neither data set contains a nondetect, and at least one data set is not normally distributed; or;

(b) At least one data set contains one or more nondetects (but not 100 percent NDs in both data sets).

Although the normal distribution is not assumed, the WRS test does assume that the two data distributions have approximately the same shape and the only difference between them is a shift in the mean. When no nondetects are present, the assumption of similar shape can be verified qualitatively by comparing the histograms or box plots of the two data sets (Appendix K2). Example K6-3 considers this situation.

There is no simple method available to evaluate the power of the WRS test. The method described in the USEPA Guidance Document[16] could be used in consultation with a statistician.

Example K6-3

Consider lead concentration data shown in Table K6.3 for disturbed and undisturbed watersheds. The application of the methods described in Appendix K2 revealed no outliers. Both data sets contain some nondetects. The WRS test is appropriate to use in this case to evaluate the differences between the means of the two populations.

The JMP software provides for the application of WRS test under the "Wilcoxon Test" option in the nonparametric ANOVA menu. The results of the WRS test for this example are shown in Figure K6-7. The significance level, p, is listed as "Prob>$|Z|$" under the normal approximation. Note that this is a two-tailed probability, appropriate when the alternative hypothesis is defined for the condition that the two population means are different without regard to which mean is higher or lower. For the paired watershed monitoring approach, the interest is only on the one-tailed; that is, when the disturbed watershed mean is higher than the undisturbed watershed mean. For one-tailed comparison, the significance level, p, is half of "Prob>$|Z|$" listed in the JMP results if the disturbed watershed has a higher "Score Mean." Conversely, if undisturbed watershed has a higher "Score Mean," the one-tailed significance level, p, is (1 - half of "Prob>$|Z|$"). For this example, the one-tailed p-value is half of 0.0031 (since disturbed watershed has a higher "Score Mean"), and equal to 0.0016. Assuming that the acceptable risk of false rejection, α, is set to 0.05, and since $p < \alpha$, one will reject the null hypothesis and accept the alternative hypothesis. In other words, the disturbance appears to have a significant adverse impace on water quality. Note for Caltrans studies, the 90 percent confidence level should be used.

[16] USEPA. 1994. Statistical Methods for Evaluating the Attainment of Cleanup Standards. Volume 3: Reference-Based Standards for Soils and Solid Media. EPA 230-R-94-004.

Table K6.3 Lead Concentration Data for Example K6-3

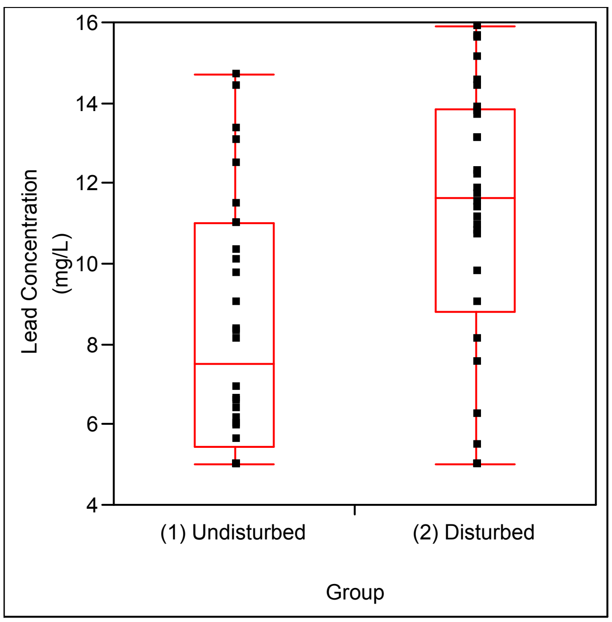
Oneway Analysis of Lead Concentration (mg/L) By Group

Disturbed Watershed Lead Concentration (mg/L)

<5	10.83	13.12
<5	10.94	13.68
<5	11.17	13.8
5.5	11.41	13.89
6.25	11.52	14.41
7.56	11.75	14.54
8.12	11.86	15.15
9.04	12.19	15.62
9.8	12.32	15.68
10.73	13.11	15.92

Undisturbed Watershed Lead Concentration (mg/L)

<5	6.18	10.11
<5	6.42	10.32
<5	6.59	11.02
<5	6.65	11.03
<5	6.92	11.48
<5	8.12	12.52
5.01	8.3	13.06
5.61	8.39	13.38
5.97	9.02	14.43
6.01	9.78	14.71



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
(1) Undisturbed	30	714.500	23.8167	-2.962
(2) Disturbed	30	1115.50	37.1833	2.962

2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
1115.5	2.96187	0.0031

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
8.8166	1	0.0030

Figure K6-7 WRS Test Result for Example K6-3

Appendix K7 How to Compare Two Paired Data Sets

K7.1 Purpose and Organization

The purpose of this appendix is to present statistical methods to compare two paired data sets and draw conclusions regarding whether observed differences in the two data sets are statistically significant. In BMP studies, paired data sets arise when monitoring approaches such as influent-effluent monitoring and before-after monitoring are used. For example, in an influent-effluent monitoring approach, BMP structures may be placed at several locations. Water samples are collected from the flow entering into, and exiting from, each BMP structure. Such paired sampling designs are useful to block out sources of background noise and focus on the effect being studied. For example, in influent-effluent monitoring, the percent reduction in the effluent concentration for a given storm event would be mainly due to the BMP effectiveness and may not be affected by other factors such as highway traffic and prior maintenance at the time of the storm event. Consequently, for paired sampling designs, the data variability is reduced and a greater power of detecting differences is achieved.

Typical study questions of interest in the analysis of two paired data sets are:

- Is the BMP effective in reducing pollutant concentration?
- Are average pollutant concentrations measured before and after a particular maintenance practice different?

In this appendix, a decision flowchart is presented to guide the user in the selection of an appropriate statistical method depending on the characteristics of each data set. An overview of each method is presented and examples related to BMP studies are provided to illustrate the use of each method.

Upon completion of the comparison tests described in this appendix, the Effluent Probability Method should be employed. A discussion of this method [taken from the ASCE Urban Stormwater BMP Performance Monitoring, Section 2.9.3 (ASCE 2002)] is described herein. This is a useful approach to quantifying BMP efficiency by examining either a cumulative distribution function of influent and effluent quality or a standard parallel probability plot. Before any efficiency plots are generated, appropriate non-parametric (or if applicable parametric) statistical tests should be conducted to indicate if any perceived differences in influent and effluent mean event mean concentrations are statistically significant (the level of significance should be provided, instead of just noting if the result was significant, assume a 90% confidence level).

The Effluent Probability Method is straightforward and directly provides a clear picture of the ultimate measure of BMP effectiveness, effluent water quality. The most useful approach for examining these curves is to plot the results on a standard parallel probability plot. A normal probability plot should be generated showing the log transform of both inflow and outflow EMCs for all storms for the BMP. If the log transformed data deviates significantly from normality, other transformations can be explored to determine if a better distributional fit exists. Figure K7-1 shows two types of results that can be observed when plotting pollutant reduction observations on probability plots. The plot for suspended solids (particulate residue) shows that SS are highly removed over influent concentrations ranging from 20 to over 1,000 mg/L. A simple calculation of "percent removal" would not show this consistent removal over the full range of observations. In contrast, the plot for total dissolved solids (filtered residue) shows poor removal of TDS for all concentration conditions. The "percent removal" for TDS would be close to zero and no additional surprises are indicated on this plot.

Water quality observations do not generally form a straight line on normal probability paper, but do (at least from about the 10th to 90th percentile level) on log-normal probability plots. This indicates that the samples generally have a log-normal distribution as described previously in this document and many parametric statistical tests can often be used (e.g., analysis of variance), but only after the data is log-transformed. These plots indicate the central tendency (median) of the data, along with their possible distribution type and variance (the steeper the plot, the smaller the COV and the flatter the slope of the plot, the larger the COV for the data). Multiple data sets can also be plotted on the same plot (such as for different sites, different seasons, different habitats, etc.) to indicate obvious similarities (or differences) in the data sets. Most statistical methods used to compare different data sets require that the sets have the same variances, and many require normal distributions. Similar variances are indicated by generally parallel plots of the data on the probability paper, while normal distributions would be reflected by the data plotted in a straight line on normal probability paper.

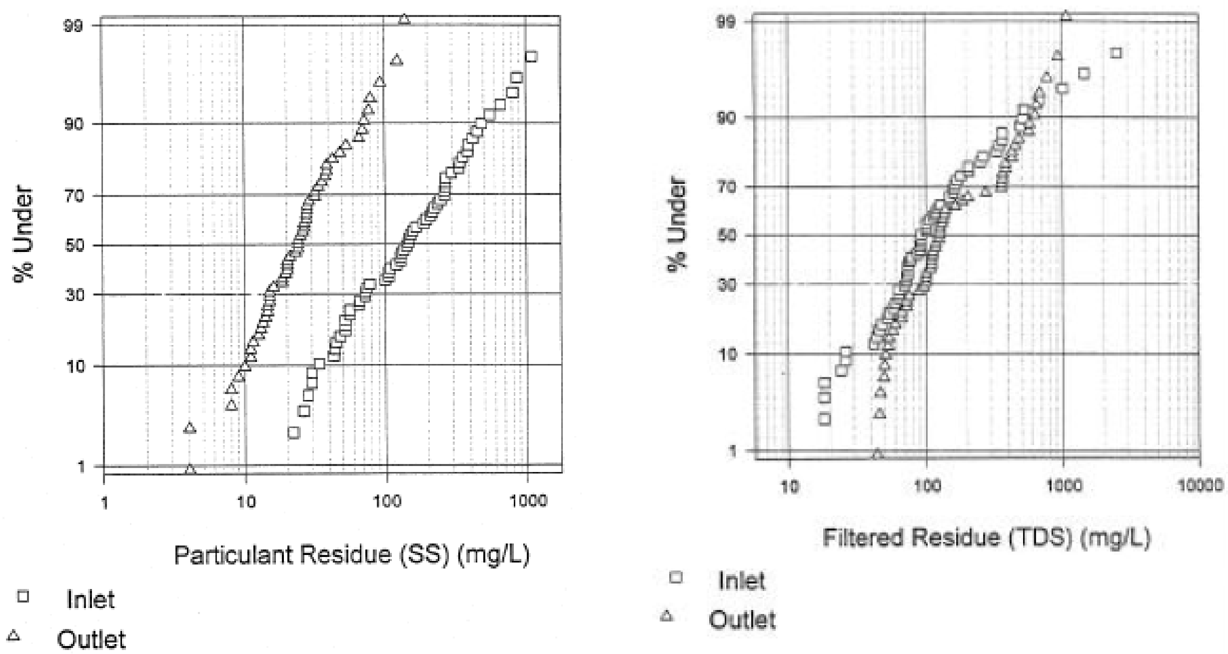


Figure K7-1 Sample Probability Plots for Suspended Solids (SS) and Total Dissolved Solids

K7.2 Decision Flowchart

Data for two paired data sets can be reduced to a single data set by taking differences between each pair of observations. The choice of an appropriate statistical test then depends on whether nondetects are present and the distribution of the differences. Figure K7-2 shows a flowchart to select an appropriate statistical test for different situations. The main pathways of the flowchart are discussed below.

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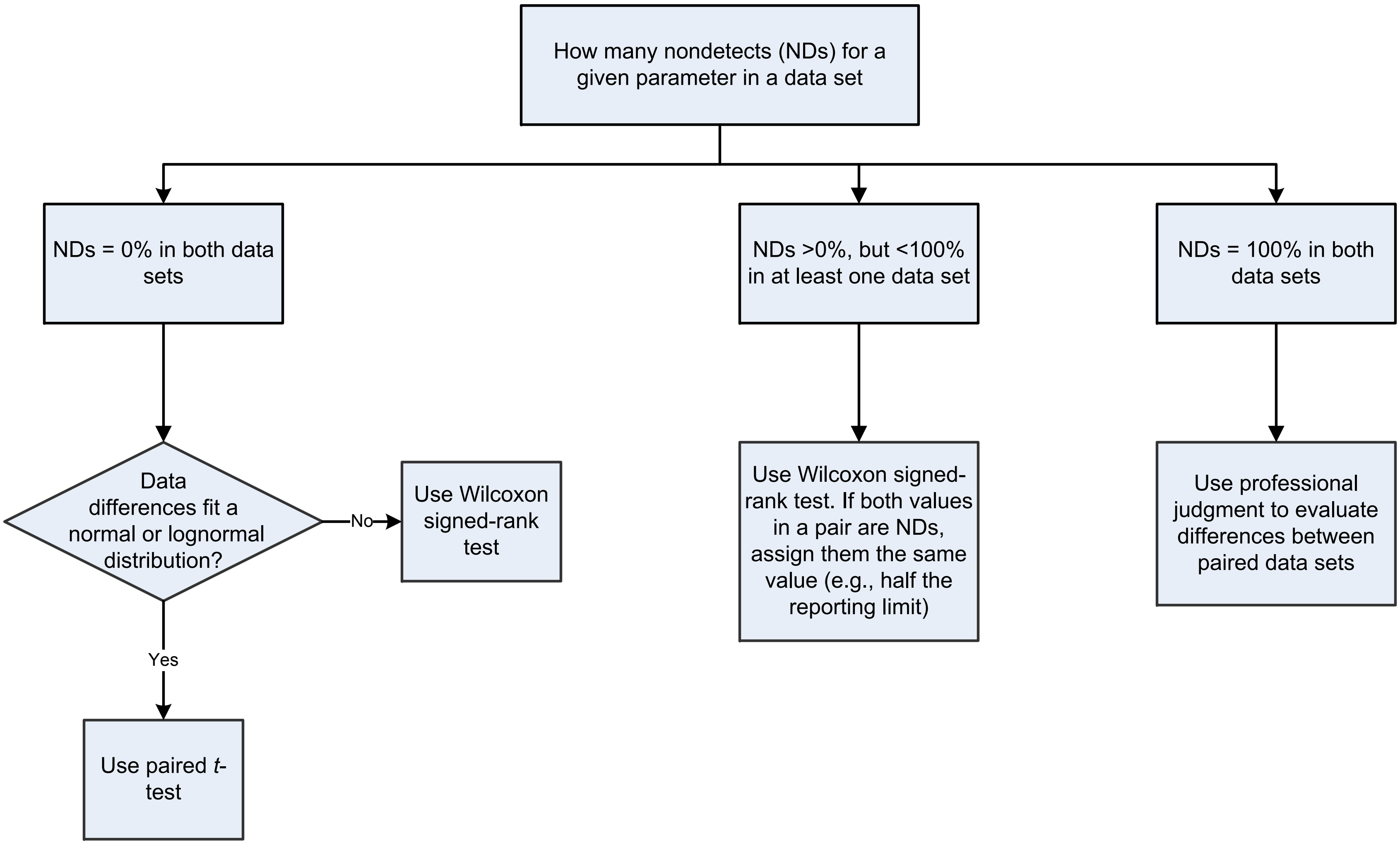

Figure K7-2 Select an Appropriate Statistical Method for Comparing Two Paired Data Sets

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K7.3 Neither of the Two Paired Data Sets Contains Any Nondetects

If the original or log-transformed differences can be assumed to follow a normal distribution, the paired *t*-test can be used on the differences between the two paired data sets. The assumption of a normal distribution can be verified through graphical methods described in Appendix K2 (histogram and normal probability plot) and the formal Shapiro-Wilk W test described in Appendix K4. If neither the original nor the log-transformed data can be assumed to follow a normal distribution, a nonparametric method that does not assume a specific distribution should be used. One such nonparametric test is called the Wilcoxon signed-rank test. This test assumes that the distribution of the differences is symmetric, but not necessarily normal. The assumption of a symmetric distribution can be verified through a histogram.

K7.4 At Least One of the Two Paired Data Sets Contains More Than 0 Percent, But Less Than 100 Percent Nondetects

In this case, a nonparametric test should be used. Again, the Wilcoxon signed-rank test, available in statistical software like JMP, may be used.

K7.5 No Detects in Both Data Sets

No statistical analysis is possible for this case. Professional judgment informed by qualitative factors may be used to compare the two data sets and draw conclusions. For BMP studies, the question of whether a BMP is effective may be moot if all data are nondetects.

K7.6 Description of Statistical Tests for Comparison of Two Paired Data Sets

The flowchart in Figure K7-2 identifies the following statistical tests:

- Paired *t*-test
- Wilcoxon signed-rank test

A brief description of each test follows.

K7.6.1 Paired *t*-Test

This test can be used to evaluate the differences between two paired data sets when each data set contains only detects. The null and alternative hypotheses are defined as follows:

> Null Hypothesis, H_0: Mean difference ≤ 0 (i.e., the BMP is ineffective in reducing pollutant concentration)

Alternative Hypothesis, H_A: Mean difference > 0 (i.e., the BMP does reduce the pollutant concentration)

The key assumption for this test is that the differences between the paired observations are normally distributed. For BMP data, the percent reduction in pollutant concentration, rather than the actual difference in pollutant concentrations, is more likely to be centered on a fixed mean with a constant variance, and hence more likely to be normally distributed. The test is robust to moderate violations of the normality assumption, but not to outliers. The normality assumption can be checked with graphical methods (histogram and normal probability plot described in Appendix K2) and a formal goodness-of-fit test (Shapiro-Wilk W test described in Appendix K4). Methods described in Appendix K2 can be used to check whether the data contains potential outliers.

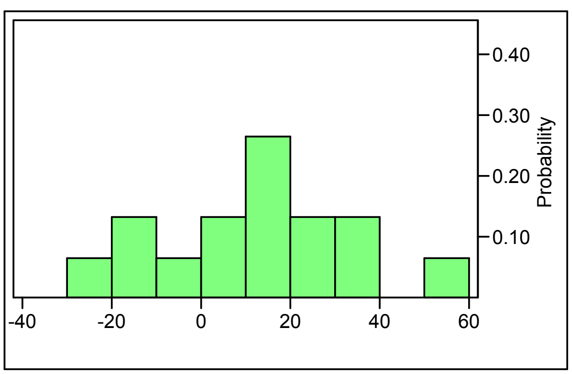
Example K7-1

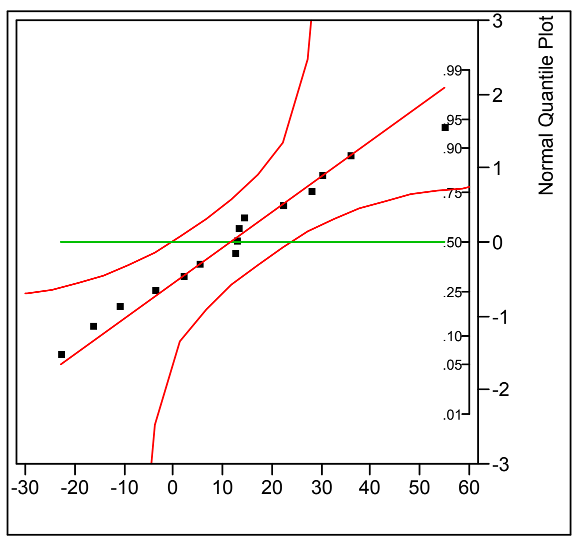
Table K7.1 shows lead concentration data collected in an influent-effluent BMP monitoring study. The influent and effluent data are paired since both measurements are taken for the same BMP. If the BMP is effective, the average percent reduction, rather than the average actual difference, in the lead concentration is likely to be constant over a range of pollutant concentrations. Table K7.1 also shows the percent reduction in lead concentration.

Figure K7-3 shows a histogram, a normal probability plot, and the results of the Shapiro-Wilk W test for the percent reduction data. The methods described in Appendix K2 were used to check for outliers; no outliers were identified. The assumption of a normal distribution appears to be reasonable for this data. Therefore, the paired *t*-test is appropriate to use. The JMP software was used to apply this test to the percent reduction data in Table K7.1. The results for both one- and two-tailed tests are shown in Figure K7-4 (see Appendix K6 for a discussion of one- and two-tailed tests). Note that the probability distribution of the percent reduction shown in Figure K7-4 highlights both tails. For this example, the interest is in assessing whether the BMP reduces the lead concentration and hence the one-tailed test is applicable. The significance level, p, of the test is 0.0225, as highlighted in the figure (because this is a one-tailed test and the paired *t*-test was performed with the interest of reduction in effluent concentrations, the one-tailed p associated with this set-up is "Prob > t"). Assuming that the acceptable risk of false rejection, α, is set to 0.05, and since $p < \alpha$, one will reject the null hypothesis and accept the alternative hypothesis that the average percent reduction in lead concentration is greater than 0 percent. In other words, the BMP is working effectively to reduce lead concentrations. Note that for Caltrans studies, the 90 percent confidence level should be used.

Table K7.1 Influent-Effluent Lead Concentration Data for Example K7-1

Station	Influent Lead Concentration (mg/L)	Effluent Lead Concentration (mg/L)	Percent Reduction
1	9.45	8.22	13
2	11.73	10.05	14.3
3	6.34	4.56	28.1
4	2.25	2.5	-11.1
5	8.53	3.84	55
6	7.68	7.53	2
7	3.87	4.5	-16.3
8	8.85	5.66	36
9	6.61	5.15	22.1
10	1.71	2.1	-22.8
11	2.68	2.35	12.3
12	0.9	0.63	30
13	2.6	2.7	-3.8
14	9.07	7.88	13.1
15	3.7	3.5	5.4





Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.982582	0.9841

Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.

Figure K7-3 Histogram, Normal Probability Plot, and Shapiro-Wilk W Test Results for Example K7-1, Percent Reduction of Zinc Concentration

Test Mean=value

Hypothesized Value	0
Actual Estimate	11.82
Df	14
Std Dev	20.7985

	t Test
Test Statistic	2.2011
Prob > |t|	0.0450
Prob > t	0.0225
Prob < t	0.9775

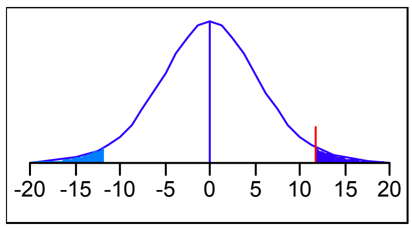


Figure K7-4 Paired t-Test Results for Example K7-1, Percent Reduction of Zinc Concentration

K7.6.2 Wilcoxon Signed-Rank Test

This test can be used to evaluate differences between two paired data sets when: (1) the data differences do not fit a normal or lognormal distribution, or (2) at least one data set contains nondetects (but not 100 percent NDs in both data sets). For BMP studies, the null and alternative hypotheses may be defined as follows:

> Null Hypothesis, H_0: Mean (or median) difference ≤ 0 (i.e., the BMP is ineffective in reducing pollutant concentration)

> Alternative Hypothesis, H_A: Mean (or median) difference > 0 (i.e., the BMP does reduce the pollutant concentration)

The test calculates and ranks the absolute differences between the paired observations. The sum of the positive signed ranks is used to calculate a test statistics. Since the test does not use the actual magnitude of the differences between paired observations, and instead uses only the rank and sign of the differences, one can use a simple, although approximate, procedure to handle nondetects. The procedure will be to set nondetects to half the reporting limit. This way, all pairs of data could be used for the Wilcoxon signed-rank test, thus improving the power of the test to detect differences. If the data contains multiple reporting limits, one option would be to censor the data at the highest reporting limit, but a substantial amount of useful information could be lost. It may be necessary to consult with a statistician to use a more rigorous method.

Example K7-2

For this example, the data for Example K7-1 will be modified to include some nondetects. The modified data is shown in Table K7.2. The nondetects will be replaced with half of the reporting limit.

The JMP results of the Wilcoxon signed-rank test for this example are shown in Figure K7-5. The significance level, *p*, for the test is 0.8853**,** as highlighted in the figure (because this is a one-tailed test and the Wilcoxon signed-rank test was performed with the interest of reduction in effluent concentrations, the one-tailed *p* associated with this set-up is “Prob > t” in the JMP output). Assuming that the acceptable risk of false rejection, α, is set to 0.05, and since $p > \alpha$, one cannot reject the null hypothesis. In other words, the BMP does not appear to be working effectively to reduce lead concentrations. Note for Caltrans studies, the 90 percent confidence level should be used.

Table K7.2 Influent-Effluent Lead Concentration Data for Example K7-2

Station	Influent Lead Concentration (mg/L)	Effluent Lead Concentration (mg/L)	Percent Reduction
1	9.45	8.22	13
2	11.73	10.05	14.3
3	6.34	4.56	28.1
4	2.25	2.5	-11.1
5	8.53	3.84	55
6	7.68	7.53	2
7	3.87	4.5	-16.3
8	8.85	5.66	36
9	6.61	5.15	22.1
10	<0.5	2.1	-740
11	<0.5	2.35	-840
12	<0.5	0.63	-152
13	<0.5	2.7	-980
14	<0.5	7.88	-3052
15	<0.5	3.5	-1300

Test Mean=value

Hypothesized Value	0
Actual Estimate	-461.39
Df	14
Std Dev	847.455

	t Test	Signed-Rank
Test Statistic	-2.1086	-22.0000
Prob > |t|	0.0535	0.2293
Prob > t	0.9733	0.8853
Prob < t	0.0267	0.1147

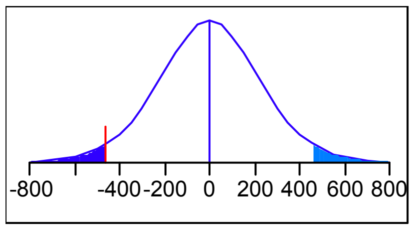


Figure K7-5 Wilcoxon Signed-Rank Test Results for Example K7-2, Percent Reduction of Zinc Concentration

Appendix K8 How to Compare Three or More Independent Data Sets

K8.1 Purpose and Organization

The purpose of this appendix is to present statistical methods to compare three or more independent data sets and draw conclusions regarding whether observed differences in the data sets are statistically significant. Typical study questions of interest in the analysis of three or more independent data sets are:

- Four pilot BMPs are close to each other. Are the influent water quality characteristics different from each other or essentially the same? If the BMPs behave differently, which specific BMPs are different from others?
- Given influent and effluent data for three pilot BMPs of the same type, how can one tell whether they are all operating in an equivalent manner?
- Three different downstream watersheds each with a BMP are being monitored for certain pollutants. Are the average pollutant concentrations in the three watersheds similar or significantly different?

In this appendix, a decision flowchart is presented to guide the user in the selection of an appropriate statistical method depending on the characteristics of each data set. An overview of each method is presented and examples related to BMP studies are provided to illustrate the use of each method.

K8.2 Decision Flowchart

The statistical methods to compare three or more independent data sets fall under the category of Analysis of Variance (ANOVA). The Student's *t*-test, described in Appendix K6 for comparison of two independent data sets, is a special case of ANOVA methods. As in Appendix K6, the choice of an appropriate statistical method depends on percentage of nondetects in the different data sets and the probability distribution that can be assumed for each data set. Figure K8-1 provides a flowchart to guide the user in the selection of an appropriate statistical method depending on the characteristics of each data set. The main pathways of the flowchart are discussed below. The details of each method and illustrative examples are provided in the next section.

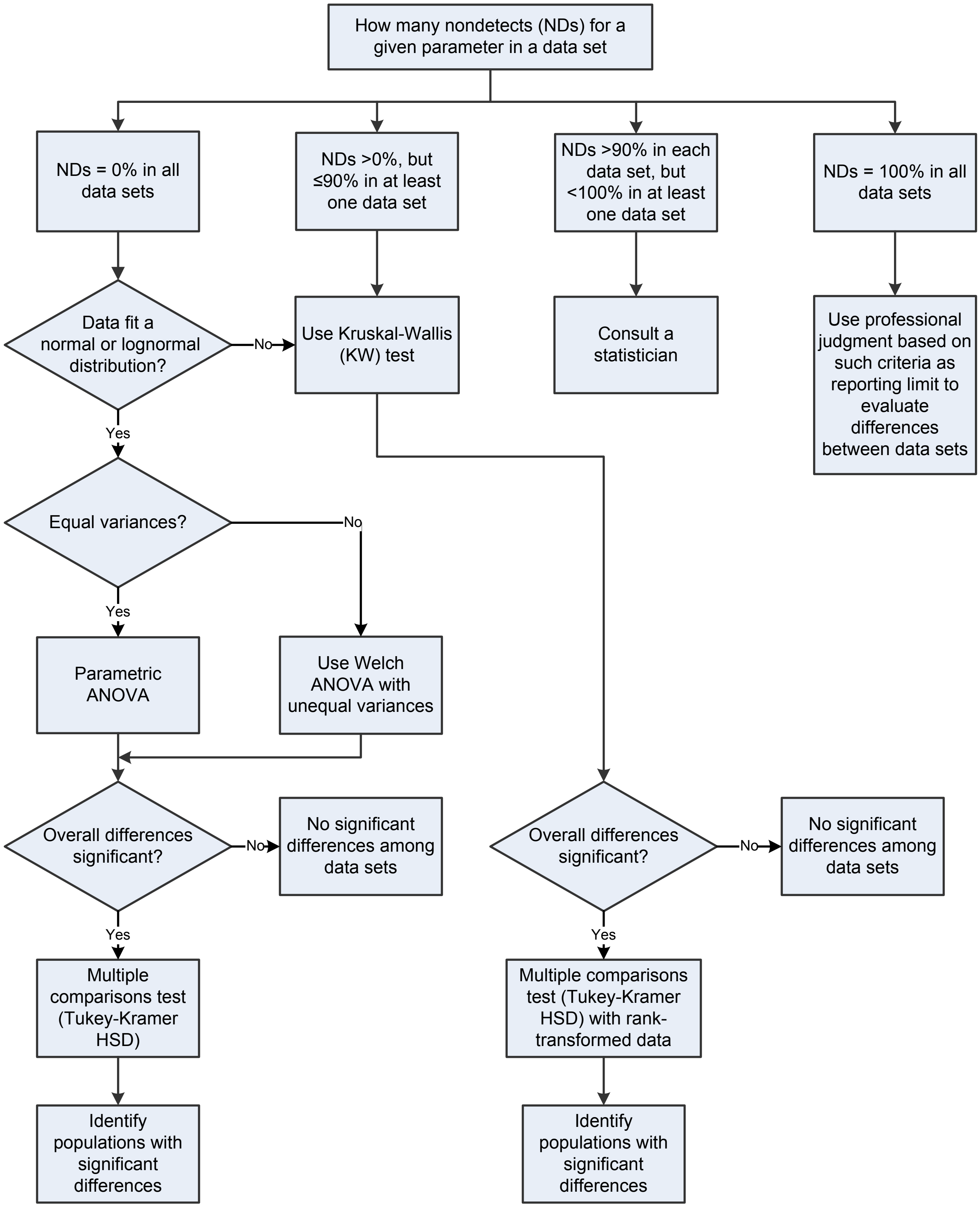


Figure K8-1 Select an Appropriate Statistical Method for Comparing Three or More Independent Data Sets

K8.3 No Nondetects in Any Data Set

If there are no nondetects in any of the data sets, the possibility of using a parametric method (i.e., one that assumes a specific probability distribution) can be explored. If the original or log-transformed data in each set can be assumed to follow a normal distribution, then further check whether the variances of the data sets are equal. If they are equal, the parametric ANOVA method can be used. If they are not equal, one can use the Welch ANOVA method, which still assumes that each data set is normally distributed, but allows for unequal variances.

If the parametric or Welch ANOVA methods show the differences among the data sets are statistically significant, the next step is to identify the specific data sets which are different from other data sets. This part of the ANOVA is called the *multiple comparisons test.* One such test is the Tukey-Kramer Honestly Significant Difference (HSD) test for making multiple comparisons. This test will be described in the next section.

If a normal distribution cannot be assumed for one or more data sets, a nonparametric method should be used. One common method in this situation is the Kruskal-Wallis (KW) test. For the multiple comparisons test in this case, the rank-transformed data should be used for the Tukey-Kramer HSD test.

K8.3.1   Nondetects are Greater than 0 Percent, but Less Than 90 Percent in at Least One Data Set

In this case, the use of a nonparametric method is recommended. Again, the KW test and the Tukey-Kramer HSD test with rank-transformed data are recommended.

K8.3.2   Nondetects are Greater than 90 Percent in Each Data Set, but Less Than 100 Percent in at Least One Data Set

When the percentage of nondetects is high (>90 percent), the location (mean or median) of a data set is not well defined. Hence, a method that tests for a shift in location would not be reliable, even when a nonparametric method is used. In this case, no simple method is available and consultation with a statistician may be necessary to investigate the use of an advanced method such as logistic regression for nominal response.

K8.3.3   No Detects in Any Data Set

No statistical analysis is possible for this case. Professional judgment informed by qualitative factors may be used to compare the data sets and draw conclusions.

K8.4 Description of Statistical Tests for Comparison of Three or More Independent Data Sets

The flowchart in Figure K8-1 identifies the following statistical tests:

- Parametric ANOVA (equal variances)
- Welch ANOVA (unequal variances)
- Tukey-Kramer HSD test for multiple comparisons
- Kruskal-Wallis (KW) test

A brief description of each test follows.

K8.4.1 Parametric ANOVA (Equal Variances)

This test can be used to evaluate the difference between the means of three or more independent data sets when the sample data contain no nondetect measurements. The key assumptions made in this test are:

- Each data set (in the original or log-transformed scale) follows a normal distribution; and
- The variances of the data sets are equal.

The test is robust to moderate violations of the normality assumption, but not to large inequalities of variances. It is also not robust against outliers because sample means and standard deviations are sensitive to outliers. The normality assumption can be checked with graphical methods (histogram and normal probability plot described in Appendix K2) and a formal goodness-of-fit test (Shapiro-Wilk W test described in Appendix K4). The Levene's test described in Appendix K4 can be used to test the equality of variances. Methods described in Appendix K2 can be used to check whether the data contains potential outliers.

The ANOVA method belongs to the class of hypothesis testing methods. As such, the basic concepts of hypothesis testing and the flowchart of the main steps in performing hypothesis testing, which were described in Appendix K6, apply to ANOVA. Specifically, the significance level, p, of ANOVA is the key statistics to interpret the results. The smaller the p, the greater are the differences between the population means and the smaller is the risk of false rejection; that is, incorrectly concluding that the population means are different when, in fact, they are the same.

Example K8-1

The effectiveness of three different BMPs in a similar environmental setting is to be evaluated. The influent-effluent monitoring is used to obtain data on percent reduction in lead concentrations, which is shown in Table K8.1. Is the average percent reduction about the same for the three BMPs?

Let μ_1, μ_2, and μ_3 denote the population mean percent reduction in lead concentration for the three BMPs. Then, the null and alternative hypotheses are defined as follows:

Null hypothesis, H_0: $\mu_1 = \mu_2 = \mu_3$ (i.e., the three BMPs perform similarly)

Alternative hypothesis, H_A: One or more population means are different from others

Figure K8-2 shows a histogram, a normal probability plot, and the results of the Shapiro-Wilk W test for each data set. The assumption of a normal distribution appears to be reasonable for each data set. Figure K8-3 shows a box plot for the three data sets and the results of the Levene's test for equality of variance. The assumption of equal variance for the three data sets appears to be reasonable. Also the methods described in Appendix K2 were applied to check for outliers and no outliers were identified. Therefore, it is appropriate to use the parametric ANOVA to evaluate differences in the population means.

The JMP software was used to perform the parametric ANOVA. The results are shown in Figure K8-4. The key part of the results is the significance level, p, which is labeled "Prob>F" in the JMP output. For the example, p is <0.0001 as highlighted in Figure K8-4. Assume that an acceptable risk of false rejection, α is set to its typical value of 0.05, and since $p < \alpha$, one will reject the null hypothesis and accept the alternative hypothesis that the percent reduction in lead concentration is different among the BMPs. Note for Caltrans studies, the 90 percent confidence level should be used.

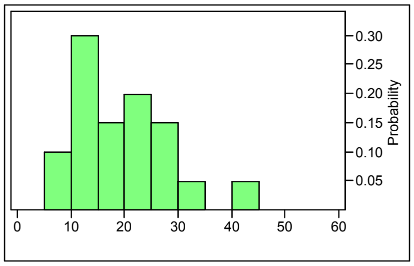
Since the conclusion of ANOVA is that the three means are not equal (i.e., the three BMPs do not perform similarly), the next step in the analysis is to identify which BMPs perform differently. This step involves performing the multiple comparisons test, which is described next.

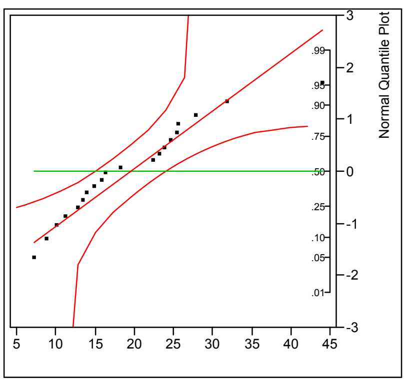
Table K8.1 Percent Reduction in Lead Concentration Data for Example K8-1

Percent Reduction in Lead Concentration for Different BMPs

BMP 1	BMP 2	BMP 3
7.3	9	17.1
8.9	9.5	18.1
10.2	9.7	18.3
11.2	10.5	20
12.9	11.2	25.1
13.5	17	25.8
14	17.1	27
14.9	18.5	29.4
15.8	18.6	30.2
16.3	19.5	31.6
18.2	19.8	31.8
22.4	20.6	33.5
23.3	21.2	34
23.8	21.5	37.8
24.6	22.1	38
25.4	22.3	42.8
25.7	22.3	43.9
27.9	31.7	44.7
31.8	31.9	51.5
44.1	39.8	57.7

Distributions
BMP 1



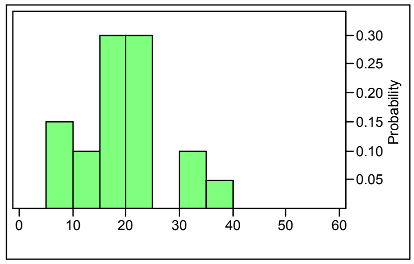


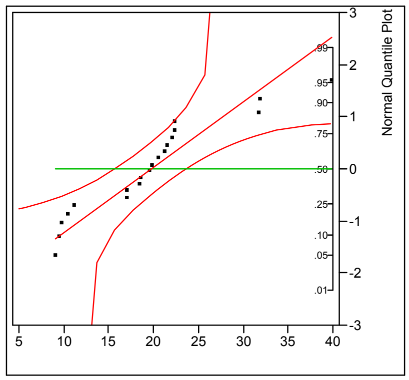
Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.928649	0.1454

Distributions
BMP 2



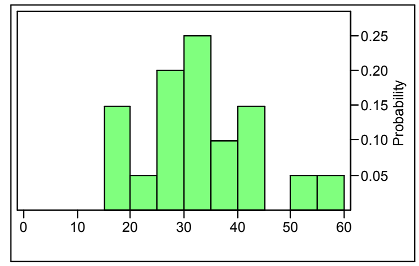


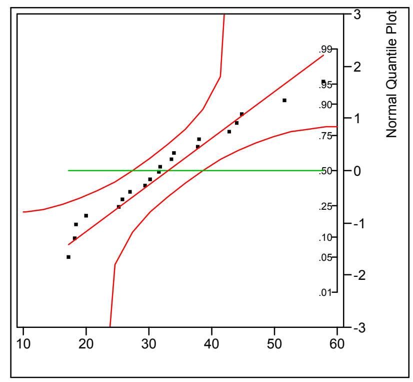
Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.904780	0.0507

Distributions
BMP 3



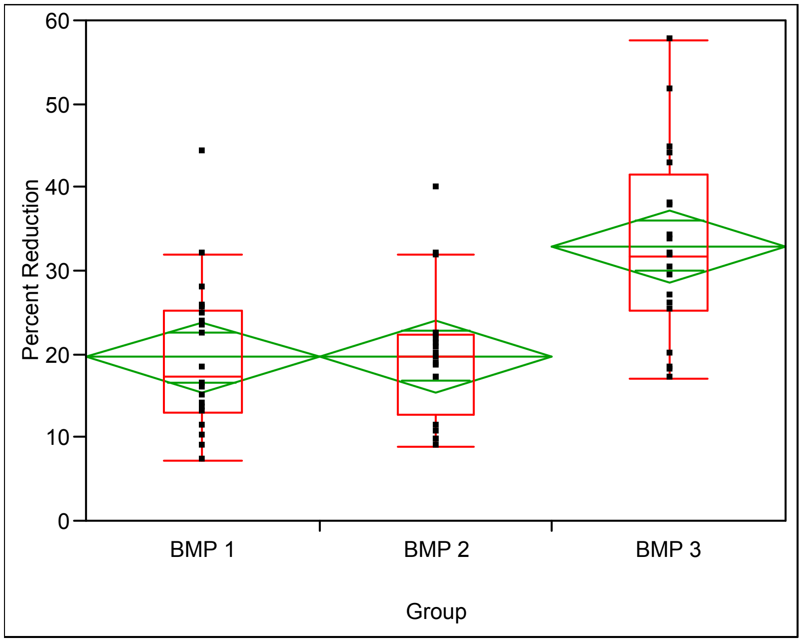


Goodness-of-Fit Test

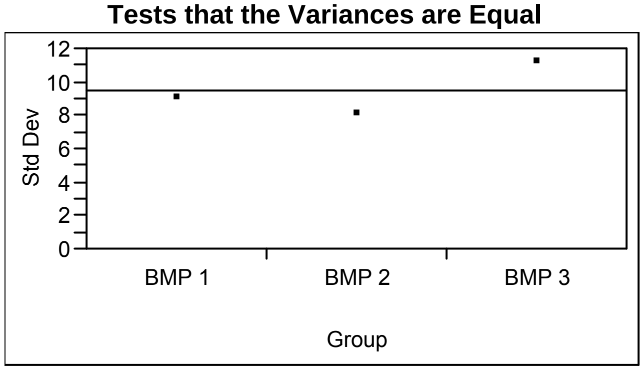
Shapiro-Wilk W Test

W	Prob<W
0.959923	0.5423

Figure K8-2 Histogram, Normal Probability Plot, and Shapiro-Wilk W Test Results for Example K8-1



Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
BMP 1	20	9.00450	7.251000	7.110000
BMP 2	20	7.99539	5.630000	5.630000
BMP 3	20	11.20992	8.766500	8.655000

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	1.0378	2	57	0.3608
Brown-Forsythe	1.2186	2	57	0.3032
Levene	1.4607	2	57	0.2406
Bartlett	1.1147	2	.	0.3280

Figure K8-3 Box Plot and Levene's Test Results for Example K8-1

Oneway Anova
Summary of Fit

Rsquare	0.313289
Adj Rsquare	0.289194
Root Mean Square Error	9.498589
Mean of Response	24.07167
Observations (or Sum Wgts)	60

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Group	2	2346.2003	1173.10	13.0022	<.0001
Error	57	5142.7215	90.22		
C. Total	59	7488.9218			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
BMP 1	20	19.6100	2.1239	15.357	23.863
BMP 2	20	19.6900	2.1239	15.437	23.943
BMP 3	20	32.9150	2.1239	28.662	37.168

Figure K8-4 Parametric ANOVA Results for Example K8-1

K8.4.2 Welch ANOVA (Unequal Variances)

If each data set (in the original or log-transformed scale) follows a normal distribution, but the variances of the data sets are found to be significantly different (using the methods described in Appendix K4), the Welch ANOVA test should be used. This test is available in statistical software packages, such as JMP. The results of this test are organized the same way as those shown in Figure K8-4. Conclusions regarding whether the population means are the same or significantly different are drawn based on the significance level, p, which is labeled “Prob>F” in the JMP output. Because the results of the Welch ANOVA are displayed and interpreted the same way as those for the parametric ANOVA with equal variances, a separate example of this test is not shown.

K8.4.3 Tukey-Kramer HSD Test for Multiple Comparisons

This test is applied to find out which population means are different if the ANOVA shows that the population means are not equal. For three or more populations, there will be multiple pairs of population means and the difference in the means for each pair needs to be tested. Each such test would be subject to a risk of false rejection. As the number of pairs to be compared increases, the risk of false rejection for at least one of the pairs is higher than the risk of false rejection for any one single pair. This is analogous to making multiple coin tosses and finding the probability of observing heads. The probability of a head coming up on any single toss of a fair coin is 0.5. However, if many tosses were to be made, the probability of getting a head on *at least* one of the tosses would be higher. It is desirable to make sure that the overall risk of false rejection for all pairs of means is controlled at a specified level, α (i.e., the probability (confidence) of reaching the correct conclusion of no difference among all pairs of population means when, in fact, all population means are the same would be (1-α)). The Tukey-Kramer HSD test is designed to control the total risk of false rejection at the specified level, α. Equivalently, it is designed to provide the overall confidence of (1-α) in reaching the correct conclusion of no difference when all population means are the same. Its use is best illustrated with an example for the case when the parametric ANOVA is valid to use. The flowchart in Figure K8-1 shows that the Tukey-Kramer HSD test is also used on rank-transformed data following a significant result of the KW test. The use of rank-transformed data in the Tukey-Kramer HSD test is discussed in a following section.

Example K8-2

For this example, the data from Example K8-1 involving three BMPs will be used. As discussed above, the parametric ANOVA showed that the means of the three BMPs are not equal. Now, one wants to find out which BMP(s) have different means. Figure K8-5 shows the results of the Tukey-Kramer HSD test, which were obtained using the JMP software. The overall risk of false rejection, α, is controlled at 0.05 as shown in Figure K8-5. Each BMP is assigned one or more letters. The BMPs that do not have a common letter have significantly different means. BMP 3 has a letter “A” and does not share the same letter with BMP 1 and BMP 2 (which both have a letter “B”), which means that BMP 3 is significantly different from BMP 1 and BMP 2, while BMP 1 and BMP 2 are similar to each other. Note for Caltrans studies, the 90 percent confidence level should be used.

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.40642	0.05

Abs(Dif)-LSD	BMP 3	BMP 2	BMP 1
BMP 3	-7.2282	5.9968	6.0768
BMP 2	5.9968	-7.2282	-7.1482
BMP 1	6.0768	-7.1482	-7.2282

Positive values show pairs of means that are significantly different.

Level			Mean
BMP 3	A		32.915000
BMP 2		B	19.690000
BMP 1		B	19.610000

Levels not connected by same letter are significantly different.

Level	- Level	Difference	Lower CL	Upper CL
BMP 3	BMP 1	13.30500	6.07678	20.53322
BMP 3	BMP 2	13.22500	5.99678	20.45322
BMP 2	BMP 1	0.08000	-7.14822	7.30822

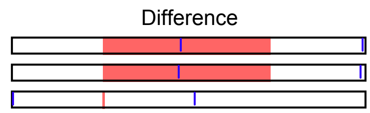


Figure K8-5 Tukey-Kramer HSD Test Results for Example K8-2

K8.4.4   Kruskal-Wallis (KW) Test

The KW test is the nonparametric equivalent of the parametric ANOVA. It is used when at least one data set contains one or more nondetects or when at least one data set is not normally distributed.

> **Example K8-3**
>
> Data from Example K8-1 will be used in this example; however, assume that some of the measurements are nondetects. Table K8.2 shows the data that will be used for this example.
>
> Figure K8-6 shows the results of the JMP software for this example. The significance level, p, of the test is 0.0004, as highlighted in the figure. Assuming that the acceptable risk of false rejection, α, is set to 0.05, and since $p < \alpha$, one will reject the null hypothesis and accept the alternative hypothesis that the average percent reduction in lead concentration is different among the BMPs. Note for Caltrans studies, the 90 percent confidence level should be used.

Table K8.2 Percent Reduction in Lead Concentration Data for Example K8-3

Percent Reduction in Lead Concentration for Different BMPs

BMP 1	BMP 2	BMP 3
<5	<5	<5
<5	<5	18.1
<5	<5	18.3
11.2	<5	20
12.9	<5	25.1
13.5	17	25.8
14	17.1	27
14.9	18.5	29.4
15.8	18.6	30.2
16.3	19.5	31.6
18.2	19.8	31.8
22.4	20.6	33.5
23.3	21.2	34
23.8	21.5	37.8
24.6	22.1	38
25.4	22.3	42.8
25.7	22.3	43.9
27.9	31.7	44.7
31.8	31.9	51.5
44.1	39.8	57.7

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
BMP 1	20	487.500	24.3750	-1.916
BMP 2	20	480.000	24.0000	-2.034
BMP 3	20	862.500	43.1250	3.958

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
15.7357	2	0.0004

Figure K8-6 Kruskal-Wallis (KW) Test Results for Example K8-3

If the KW test shows a significant result (i.e., the significance level of the KW test is less than the specified α), one should assess which population means are different using the Tukey-Kramer HSD test on the rank-transformed data. Statistical software packages such as JMP provide a procedure to obtain the ranks of the original data. The JMP procedure calculates the average rank of all tied observations and assigns this rank to each tied observation. To use this procedure for a data set containing nondetects, all nondetects are set equal to zero. JMP will assign the average rank of all nondetects to each nondetect. Once the rank-transformed data are obtained, the Tukey-Kramer HSD test is applied the same way as described above for the parametric ANOVA. Tukey-Kramer HSD test results for Example K8-3 are shown in Figure K8-7.

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.40642	0.05

Abs(Dif)-LSD	BMP 3	BMP 1	BMP 2
BMP 3	-11.559	7.191	7.566
BMP 1	7.191	-11.559	-11.184
BMP 2	7.566	-11.184	-11.559

Positive values show pairs of means that are significantly different.

Level			Mean
BMP 3	A		43.125000
BMP 1		B	24.375000
BMP 2		B	24.000000

Levels not connected by same letter are significantly different.

Level	- Level	Difference	Lower CL	Upper CL
BMP 3	BMP 2	19.12500	7.5662	30.68378
BMP 3	BMP 1	18.75000	7.1912	30.30878
BMP 1	BMP 2	0.37500	-11.1838	11.93378

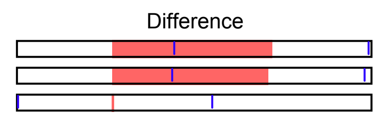


Figure K8-7 Tukey-Kramer HSD Test Results for Example K8-3

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Appendix K9 How to Develop a Linear Regression Equation

K9.1 Purpose and Organization

The purpose of this appendix is to present methods to develop a predictive relationship between a response variable y (e.g., percent removal of a pollutant concentration) and several explanatory variables $x_1, x_2, \ldots, x_m$ (e.g., storm characteristics such as rainfall amount, rainfall intensity, and antecedent weather conditions). When the predictive relationship is assumed to be linear in the explanatory variables, methods of multiple linear regression can be used. If only one explanatory variable is of interest and a linear relationship is appropriate, the method is called simple linear regression, which is a special case of multiple linear regression analysis.

A multiple linear regression equation between a response variable, y, and a set of explanatory variables, $x_1, x_2, \ldots, x_m$ has the following form:

$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_m x_m + \varepsilon$, in which

$\beta_0, \beta_1, \ldots, \beta_m$ are model parameters, called regression coefficients, and

ε = random error term, assumed to be normally distributed with a mean of zero and variance of σ^2.

The regression coefficients are estimated using the method of "least squares," which minimizes the sum of squared deviations between the measured y and its expected value over all measurements. The estimated regression coefficients are denoted as $b_0, b_1, \ldots, b_m$.; that is, $\hat{\beta}_i = b_i$.

K9.2 Steps to Perform Multiple Linear Regression

The main steps in performing multiple linear regression are:

1. Perform a screening analysis to filter potential explanatory variables.
2. Run stepwise multiple regression analysis and select a model for further investigation.
3. Verify key assumptions of a multiple linear regression model.
4. Use the selected regression model to predict the response variable for specified values of the explanatory variables.

A common example will be used throughout this appendix so that each of the four steps can be illustrated based on the conclusions drawn from the previous step. The data for this example are presented first and then each of the steps identified above are described. The final section provides a discussion of how regression analysis could be used to compare the performance of different BMPs based on predicted effluent concentrations.

Example K9-1

Soil properties and site characteristics control many of the hydrologic and sediment aspects of stormwater, which in turn affect infiltration and stormwater runoff volume. The estimation of stormwater runoff volume is directly related to the runoff coefficient. The purpose of the statistical analysis described in this example was to derive a predictive relationship between the runoff coefficient and relevant soil and site characteristics. The results of the analysis could be used to identify the soil and site characteristics that have the most influence on the runoff coefficient and to develop effective design and construction practices to control runoff volume.

Data on relevant soil and site characteristics were collected or estimated at 23 sites. Using historical data on rainfall and runoff volume, the runoff coefficient was estimated at each site. Table K9.1 lists the data on runoff coefficient and relevant soil and site characteristics collected at the 23 sites.

Table K9.1 Runoff Coefficient and Relevant Soil and Site Characteristics Data for Example K9-1

Site/System	Average Runoff Coefficient	Average Strip Width (m)	Slope Inclination (%)	Average Vegetative Cover (%)	Estimated Hydraulic Residence Time (min)	Relative Compaction (%)	Dry Density (lb/ft^3)	Infiltration Rate (in/hr)	Porosity (%)	Gravel (%)	Sand (%)	Silt/Clay (%)
Sacramento System 2	**0.31**	1.1	2.2	92.5	4.58	93.5	121.6	2.96	29.2	51.8	36.9	11.3
Sacramento System 3	**0.32**	4.6	33	83.725	4.79	81.2	105.6	2.68	38.5	31.9	36.5	31.6
Sacramento System 4	**0.28**	6.6	33	91.5	5.95	79.7	103.6	2.35	39.6	32.5	36.5	31
Sacramento System 5	**0.15**	8.4	33	89.775	7.67	78.4	101.9	3.14	40.6	39.2	35.8	25
Cottonwood System 2	**0.19**	9.3	52	73.075	7.12	85.8	111.5	3.5	33.3	44	41.6	14.4
Redding System 2	**0.57**	2.2	10	79.575	4.91	93.9	129.3	1.89	27.1	39.6	48.8	11.6
Redding System 3	**0.31**	4.2	10	85.425	7.24	93	128.9	3.34	27.3	47.2	42.5	10.3
Redding System 4	**0.45**	6.2	10	87.1	8.20	88.6	122.6	4.15	30.8	34.7	52.8	12.5
San Rafael System 2	**0.13**	8.3	50	83.975	6.72	78.8	107.1	9.29	35.9	40.6	38.6	20.8
Irvine System 2	**0.39**	3.3	11	70.15	5.46	88.4	108.7	1.54	34	24.9	59.9	15.2
Irvine System 3	**0.05**	6	11	63.425	7.81	84.7	104.9	1.65	36.3	16.7	59.5	23.8
Irvine System 4	**0.16**	13	11	62.225	12.43	87.6	107.8	0.92	34.6	20.1	46.5	33.4
Yorba Linda System 2	**0.37**	1.85	14	61.05	3.59	89.2	114.7	1.26	33.4	28.1	53.4	18.5
Yorba Linda System 3	**0.51**	4.9	14	82.375	6.44	82.5	106	0.87	38.5	25.3	53.5	21.2
Yorba Linda System 4	**0.58**	7.6	14	74.45	8.38	87.7	112.7	1.57	34.6	17.2	60.6	22.2
Yorba Linda System 5	**0.17**	13	14	75.575	11.56	86.8	111.6	1.81	35.2	34.2	49.6	16.2
Moreno Valley System 2	**0.95**	2.6	13	3.05	1.13	90.7	123.4	0.72	28.9	20.3	61.5	18.2
Moreno Valley System 3	**0.95**	4.9	13	16.3	1.65	93.3	126.6	0.57	27	29.7	53	17.3
Moreno Valley System 4	**0.48**	8	13	21.575	2.22	92.9	125.8	0.94	27.5	16.5	59.1	24.4
Moreno Valley System 5	**0.51**	9.9	13	18.225	2.52	93.9	127.3	1.04	26.6	13.7	70.2	16.1
San Onofre System 2	**0.45**	1.3	8	81.2	3.43	95.9	122.7	2.25	27.4	19	63.8	17.2
San Onofre System 3	**0.27**	5.3	10	73.8	7.46	88.5	114.7	1.25	32.2	27.1	56.8	16.1
San Onofre System 4	**0.07**	9.9	16	69.1	9.43	85.3	108.3	0.75	36	21.7	55.7	22.6

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K9.2.1 Step 1. Perform a Screening Analysis to Filter Potential Explanatory Variables

When a large number of potential explanatory variables have been identified, it is desirable to reduce the number of explanatory variables. A smaller number of explanatory variables helps to increase the computational efficiency of multiple regression analysis and to obtain more stable estimates of the regression coefficients. Both graphical and numerical methods are recommended to filter the potential explanatory variables.

In the graphical method, a scatterplot of the response variable against each explanatory variable is prepared. This plot is used to assess whether there is a reasonable linear relationship between the two variables. The development and interpretation of scatterplots are described in Appendix K2. If a scatterplot shows mostly random noise and little structure, the explanatory variable may be excluded from further analysis. If the scatterplot shows a nonlinear relationship, an appropriate transformation (e.g., log transformation) may be used on the response variable, the explanatory variable, or both to develop a more linear relationship between the two variables. With regard to the explanatory variables, the transformation decision may be made separately for each variable. Thus, one could have a mix of raw and transformed explanatory variables in a multiple regression equation.

In the numerical method, a correlation matrix is developed that shows the simple correlation coefficient between each pair of variables. This matrix has (m +1) rows - one row for the response variable and one row for each of the m explanatory variables. Similarly, it has (m +1) columns. Thus, each cell in this matrix represents one pair of variables. In each cell, the matrix displays simple correlation coefficient between the two variables represented by that cell. This coefficient measures the strength of the linear relationship between two variables. If there is an exact linear relationship between two variables, the correlation coefficient is 1 or –1, depending on whether the variables are positively or negatively correlated. If there is no linear relationship between the two variables, the correlation coefficient tends toward zero.

The JMP software generates a matrix table to show the correlation coefficients between all pairs of variables. This table should be used to screen out explanatory variables with relatively low correlation with the response variable. Two criteria may be used to screen out explanatory variables.

The first screening criterion is based on a threshold for the correlation coefficient between the response variable and the explanatory variable under consideration. A reasonable rule of thumb is to exclude the explanatory variables with a correlation coefficient less than or equal to 0.2.

The square of the correlation coefficient defines the proportion of the variability in the response variable that is explained by the explanatory variable. Thus, a correlation coefficient of less than 0.2 would mean that less than four percent of the variability in the response variable would be explained by the explanatory variable and, hence, this explanatory variable could be considered to be of little value in developing a predictive equation for the response variable.

The second screening criterion is based on the concept that if two potential explanatory variables are highly correlated, both variables in the regression equation could create numerical as well interpretation problems. A reasonable rule of thumb is to retain *only* one of the two explanatory variables that have a correlation coefficient of 0.9 or greater with each other.

The results of completing the screening analysis for Example K9-1 are discussed next.

Results of Step 1 for Example K9-1

Table K9.2 shows the correlation coefficients between all pairs of original/log-transformed response variables and original explanatory variables. Table K9.3 shows similar results using log-transformed explanatory variables. The highest simple correlation is between the runoff coefficient and natural logarithm of hydraulic residence time (r = -0.79). Because the log-transformed explanatory variables generally show higher correlations with the raw runoff coefficient than raw explanatory variables, the subsequent regression analysis was performed using the raw runoff coefficient and the log-transformed explanatory variables.

Figure K9-1 shows the scatterplot between the runoff coefficient and natural logarithm of hydraulic residence time. The scatterplot suggests a reasonably linear relationship between the two variables with a negative correlation. That is, the runoff coefficient decreases as the hydraulic residence time increases. Similar scatterplots between the runoff coefficient and other explanatory variables should be prepared to examine the nature of the relationship between those pairs of variables.

Using the first screening criterion described above, no explanatory variables were excluded from further analysis because all correlation coefficients (in log scale of explanatory variables) with the raw runoff coefficient were higher than 0.2 (in absolute value).

The second screening criterion was applied next to the retained explanatory variables. The following pairs of explanatory variables showed a correlation coefficient of 0.9 or greater: log of dry density and log of porosity (r = -0.97), log of porosity and log of relative percent compaction (r = -0.93), and log of dry density and log of relative percent compaction (r = -0.90). Because these three variables are highly correlated with each other, only one of them should be retained for further analysis. The log of dry density was retained because, among the three variables, it showed the highest correlation with runoff coefficient.

After applying both screening criteria, the following explanatory variables were retained for further analysis:

- Ln Average Strip Width (m)
- Ln Slope Inclination (%)
- Ln Average Vegetative Cover (%)
- Ln Dry Density (lb/ft^3)
- Ln Infiltration Rate (in/hr)
- Ln Gravel (%)
- Ln Sand (%)
- Ln Silt/Clay (%)
- Ln Estimated Hydraulic Residence Time (min)

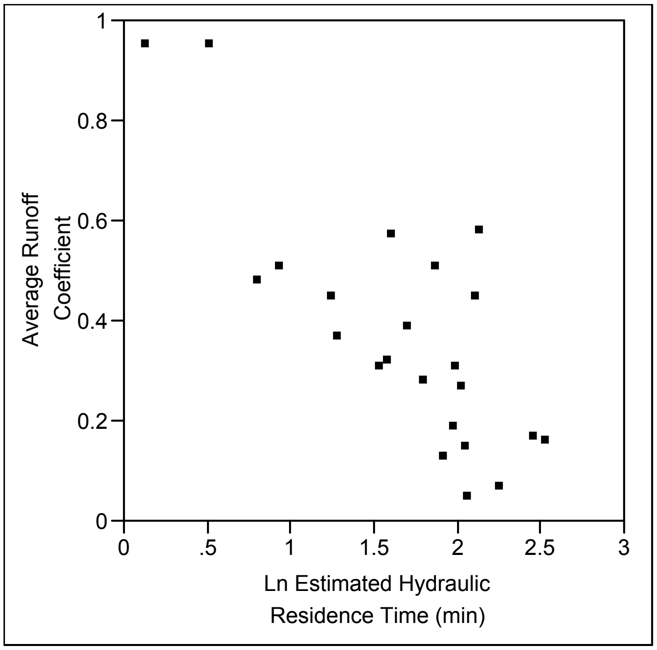


Figure K9-1 Scatterplot Between Runoff Coefficient and Natural Logarithm of Hydraulic Residence Time in Minutes

Table K9.2 Correlation Coefficients Between Original/Log-transformed Response Variable and Original Explanatory Variables

		Potential Response Variable		**Potential Explanatory Variables**										
		Average Runoff Coeff-icient	**Ln Average Runoff Coeff-icient**	**Average Strip Width (m)**	**Slope Inclin-ation (%)**	**Average Veget-ative Cover (%)**	**Relative Comp-action (%)**	**Dry Density (lb/ft3)**	**Infiltra-tion Rate (in/hr)**	**Porosity (%)**	**Gravel (%)**	**Sand (%)**	**Silt/Clay (%)**	**Est Hyd Resid-ence Time (min)**
Potential Response Variable	**Average Runoff Coefficient**	**1**	**0.9111**	-0.445	-0.3398	-0.6231	0.524	0.6204	-0.3671	-0.5659	-0.2301	0.4158	-0.2641	-0.6957
	Ln Average Runoff Coefficient	**0.9111**	**1**	-0.4779	-0.3123	-0.4104	0.5363	0.6325	-0.2821	-0.5574	-0.091	0.2972	-0.3107	-0.6588
Potential Explanatory Variables	**Average Strip Width (m)**	**-0.445**	**-0.4779**	1	0.3282	-0.0654	-0.3712	-0.36	0.0506	0.3404	-0.1828	-0.0614	0.3983	0.6387
	Slope Inclination (%)	**-0.3398**	**-0.3123**	0.3282	1	0.2222	-0.6971	-0.5027	0.6166	0.5058	0.3324	-0.5567	0.3133	0.0979
	Average Vegetative Cover (%)	**-0.6231**	**-0.4104**	-0.0654	0.2222	1	-0.44	-0.4543	0.4718	0.5044	0.561	-0.5987	-0.0002	0.5607
	Relative Compaction (%)	**0.524**	**0.5363**	-0.3712	-0.6971	-0.44	1	0.8961	-0.4033	-0.9407	-0.1427	0.5362	-0.596	-0.4385
	Dry Density (lb/ft3)	**0.6204**	**0.6325**	-0.36	-0.5027	-0.4543	0.8961	1	-0.1689	-0.9684	0.0437	0.3734	-0.6522	-0.5354
	Infiltration Rate (in/hr)	**-0.3671**	**-0.2821**	0.0506	0.6166	0.4718	-0.4033	-0.1689	1	0.1758	0.5695	-0.5351	-0.1131	0.1522
	Porosity (%)	**-0.5659**	**-0.5574**	0.3404	0.5058	0.5044	-0.9407	-0.9684	0.1758	1	0.0356	-0.4505	0.6404	0.529
	Gravel (%)	**-0.2301**	**-0.091**	-0.1828	0.3324	0.561	-0.1427	0.0437	0.5695	0.0356	1	-0.8078	-0.4031	0.1297
	Sand (%)	**0.4158**	**0.2972**	-0.0614	-0.5567	-0.5987	0.5362	0.3734	-0.5351	-0.4505	-0.8078	1	-0.2138	-0.2821
	Silt/Clay (%)	**-0.2641**	**-0.3107**	0.3983	0.3133	-0.0002	-0.596	-0.6522	-0.1131	0.6404	-0.4031	-0.2138	1	0.2231
	Est Hyd Residence Time (min)	**-0.6957**	**-0.6588**	0.6387	0.0979	0.5607	-0.4385	-0.5354	0.1522	0.529	0.1297	-0.2821	0.2231	1

Table K9.3 Correlation Coefficients Between Original/Log-transformed Response Variable and Log-transformed Explanatory Variables

		Potential Response Variable		Potential Explanatory Variables										
		Average Runoff Coeff-icient	**Ln Average Runoff Coeff-icient**	**Ln Average Strip Width (m)**	**Ln Slope Inclin-ation (%)**	**Ln Average Veget-ative Cover (%)**	**Ln Relative Comp-action (%)**	**Ln Dry Density (lb/ft3)**	**Ln Infiltra-tion Rate (in/hr)**	**Ln Porosity (%)**	**Ln Gravel (%)**	**Ln Sand (%)**	**Ln Silt/Clay (%)**	**Ln Est Hyd Resid-ence Time (min)**
Potential Response Variable	**Average Runoff Coefficient**	**1**	**0.9111**	-0.369	-0.2394	-0.7008	0.5213	0.6202	-0.4684	-0.5762	-0.2174	0.4156	-0.23	-0.7878
	Ln Average Runoff Coefficient	**0.9111**	**1**	-0.4261	-0.254	-0.4792	0.5318	0.6337	-0.2943	-0.568	-0.0821	0.292	-0.3055	-0.6796
Potential Explanatory Variables	**Ln Average Strip Width (m)**	**-0.369**	**-0.4261**	1	0.5585	0.0329	-0.471	-0.3969	-0.037	0.4024	-0.1981	-0.0447	0.4422	0.4469
	Ln Slope Inclination (%)	**-0.2394**	**-0.254**	0.5585	1	0.065	-0.722	-0.5295	0.296	0.5433	0.1151	-0.3566	0.4807	0.1424
	Ln Average Vegetative Cover (%)	**-0.7008**	**-0.4792**	0.0329	0.065	1	-0.373	-0.4442	0.579	0.4684	0.4515	-0.4726	-0.0217	0.8084
	Ln Relative % Compaction	**0.5213**	**0.5318**	-0.471	-0.722	-0.373	1	0.8965	-0.3649	-0.9297	-0.2193	0.5523	-0.6078	-0.4794
	Ln Dry Density (lb/ft3)	**0.6202**	**0.6337**	-0.3969	-0.5295	-0.4442	0.8965	1	-0.1791	-0.9741	-0.03	0.386	-0.6765	-0.5722
	Ln Infiltration Rate (in/hr)	**-0.4684**	**-0.2943**	-0.037	0.296	0.579	-0.3649	-0.1791	1	0.2075	0.6366	-0.62	-0.221	0.3976
	Ln Porosity (%)	**-0.5762**	**-0.568**	0.4024	0.5433	0.4684	-0.9297	-0.9741	0.2075	1	0.1114	-0.4387	0.639	0.5949
	Ln Gravel (%)	**-0.2174**	**-0.0821**	-0.1981	0.1151	0.4515	-0.2193	-0.03	0.6366	0.1114	1	-0.8024	-0.4325	0.2667
	Ln Sand (%)	**0.4156**	**0.292**	-0.0447	-0.3566	-0.4726	0.5523	0.386	-0.62	-0.4387	-0.8024	1	-0.1301	-0.3379
	Ln Silt/Clay (%)	**-0.23**	**-0.3055**	0.4422	0.4807	-0.0217	-0.6078	-0.6765	-0.221	0.639	-0.4325	-0.1301	1	0.1119
	Ln Est Hyd Residence Time (min)	**-0.7878**	**-0.6796**	0.4469	0.1424	0.8084	-0.4794	-0.5722	0.3976	0.5949	0.2667	-0.3379	0.1119	1

K9.2.2 Step 2. Run Stepwise Multiple Regression Analysis and Select a Model for Further Investigation

The stepwise multiple regression analysis is used to select the most efficient set of explanatory variables among those that are retained after performing the screening analysis. In this method, the analysis is performed in a series of steps to decide which explanatory variables should be included in the regression equation. At each step, the method seeks to add a variable to the equation if a certain *inclusion* criterion is met. The method also seeks to exclude a variable that is already in the equation if a certain *exclusion* criterion is met. The *inclusion* criterion relates to the additional amount of variability in the response variable that would be explained by including a new explanatory variable in the equation. Similarly, the *exclusion* criterion relates to the loss in the amount of variability in the response variable explained if an explanatory variable is excluded. Statistical software packages such as JMP or Minitab have reasonable default values for these criteria. The stepwise regression analysis stops when no new variable could be added and none of the existing variables in the equation could be excluded. The explanatory variables in the final step and the corresponding regression equation are selected for predicting the response variable for given values of the explanatory variables.

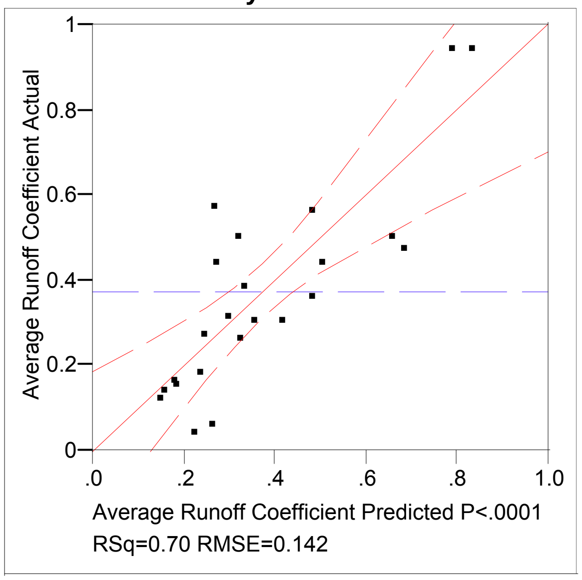
Results of Step 2 for Example K9-1

The stepwise regression analysis was performed using the JMP software package. The final step in this analysis generated the following regression equation, referred to in this appendix as Equation (1):

$$\text{Runoff coefficient} = -3.06 + 0.809 \times \ln(\text{dry density}) - 0.071 \times \ln(\text{infiltration rate}) - 0.218 \times \ln(\text{hydraulic residence time})$$

In this equation, the runoff coefficient is unitless, dry density is in lb/ft^3, infiltration rate is in inches/hour, and hydraulic residence time is in minutes.

Response Average Runoff Coefficient
Whole Model
Actual by Predicted Plot



Summary of Fit

RSquare	0.696738
RSquare Adj	0.648854
Root Mean Square Error	0.142015
Mean of Response	0.374783
Observations (or Sum Wgts)	23

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	0.8803795	0.293460	14.5507
Error	19	0.3831944	0.020168	Prob > F
C. Total	22	1.2635739		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-3.060438	2.284872	-1.34	0.1962
Ln Dry Density (lb/ft3)	0.8091372	0.469107	1.72	0.1008
Ln Infiltration Rate (in/hr)	-0.07108	0.04914	-1.45	0.1643
Ln Estimated Hydraulic Residence Time (min)	-0.218341	0.06499	-3.36	0.0033

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Ln Dry Density (lb/ft3)	1	1	0.06000215	2.9751	0.1008
Ln Infiltration Rate (in/hr)	1	1	0.04219688	2.0923	0.1643
Ln Estimated Hydraulic Residence Time (min)	1	1	0.22763894	11.2871	0.0033

Figure K9-2 Statistical Details of Regression Equation (1)

Figure K9-2 shows the JMP output for the final regression equation. The key parts of the output, highlighted in green in Figure K9-2, are described below:

- RSquare: This is the square of the coefficient of multiple correlation. It measures the proportion of the total variability in the response variable explained by the regression model. The higher the RSquare, the better is the fit of the regression model to the data. For the example, the RSquare is about 0.70, which means that about 70 percent of the site-to-site variability in the estimated runoff coefficient is explained by the regression model.
- Root Mean Square Error (RMSE): This is the standard deviation of the random error that can be attributed to the unexplained variability in the runoff coefficients for the study sites. The smaller the RMSE, the smaller is the uncertainty in predicting a value of the response variable for a new combination of the *x* variables. For the example, the RMSE is about 0.14, which means that the runoff coefficient estimated from the regression equation has an approximate (one standard deviation) accuracy of plus or minus 0.14. To assess the reasonableness of a regression model, one should report both RSquare and RMSE. Although RSquare provides an indication of how well the model fits the data, it is not sufficient to assess whether the model is reasonable for predictive purposes. Even when RSquare is relatively high, the RMSE could still be large and the range of plausible predicted values based on this RMSE too wide to be of practical use.
- Prob > F (under "Analysis of Variance"): This is the significance probability, *p*, for the regression model. It is the probability of getting the relationship between the response variable and the explanatory variables defined by the regression model by chance alone. Significance probabilities of less than 0.05 are often considered sufficient evidence that the regression model is significant. For the example, the significance probability is less than 0.0001, indicating a highly significant regression model. Therefore, this model may be selected to estimate the runoff coefficient at different sites as a function of the explanatory variables. Note for Caltrans studies, the 90 percent confidence level should be used.
- Parameter Estimates: This section of the output provides information about the estimated regression coefficients. The column labeled "Estimate" shows the mean values of the regression coefficients. The column labeled "Std Error" shows the standard error of each estimate. The column labeled "t Ratio" is the ratio (Estimate/Std Error). Higher values of the *t* ratio indicate greater significance of the regression coefficient. The column labeled "Prob>|t|" is the significance probability, *p*, for the estimated regression coefficient. Values of *p* less than 0.05 are often considered sufficient evidence that the regression coefficient is significant (i.e., it is not zero). For the example, the *p* values shown suggest that the log of hydraulic residence time is highly significant ($p = 0.0033$) and log of dry density ($p = 0.10$)

and log of infiltration rate ($p = 0.16$) are moderately significant. Note for Caltrans studies, the 90 percent confidence level should be used.

K9.2.3 Step 3. Verify Key Assumptions of a Multiple Linear Regression Model

Key assumptions of the multiple regression model are:

- The error terms (i.e., the difference between the actual and predicted values of the response variable) are normally distributed.
- The error terms have a constant variance.
- The error terms are independent (i.e., random).

These assumptions can be verified by analyzing the residuals, which are defined as the differences between the observed and predicted values of y. Statistics software packages such as JMP and Minitab provide the option of calculating and saving the residuals. These residuals can be analyzed using the graphical and numerical methods of data review described in Appendix K2.

Verify Error Terms Are Normally Distributed: The assumption of normal distribution should be verified with a normal probability plot as described in Appendix K2.

Verify Error Terms Have a Constant Variance: A plot of residuals versus the predicted values of the response variable should be prepared to assess whether the scatter of the residuals around the zero-residual line is relatively constant and does not show an increasing or decreasing trend.

Verify Error Terms Are Independent: If the response variable has been observed sequentially over time, one can plot residuals against time, even though time has not been explicitly incorporated as an explanatory variable in the model. If this plot shows a random pattern, the error terms can be considered to be independent. Conversely, if the time plot shows a systematic pattern (e.g., increasing residuals with time), this would suggest that the error terms are not independent over time and are, in fact, correlated.

If error terms are not normally distributed or do not have a constant variance, data transformation can often help in correcting both conditions. If the plot of residuals versus predicted values of the response variable shows that the variability of the residuals increases with increasing predicted values of the response variable, helpful transformations in this case are the logarithmic and square root transformations of the response variable. If any remedial measures are necessary, Steps 1 and 2 should be repeated after applying the remedial measures to the data.

Results of Step 3 for Example K9-1

Figure K9-3 shows a normal probability plot of the residuals for the regression model developed in Step 2. The plot appears to be linear and data are fitted relatively well on a straight line; hence, the residuals can be assumed to be normally distributed.

Figure K9-4 shows a plot of residuals against predicted values of the response variable. The data appear to be scattered around the zero-residual line with no specified pattern. Hence, the residuals can be assumed to have a constant variance.

Since the data for this example are not obtained in a time sequence, the check on time independence is not relevant. One can assume that the study sites for the example were selected to be sufficiently apart from each other such that they can be considered to be spatially independent. That is, if the runoff coefficient at one site is above its regression-predicted value, the runoff coefficient at any other site is not more likely to also be above its regression-predicted value.

Since the key assumptions of the regression model are verified for the example, one will assume that the regression model defined in Equation (1) is valid to predict runoff coefficients at different sites, provided the data on the explanatory variables included in the regression equation are collected.

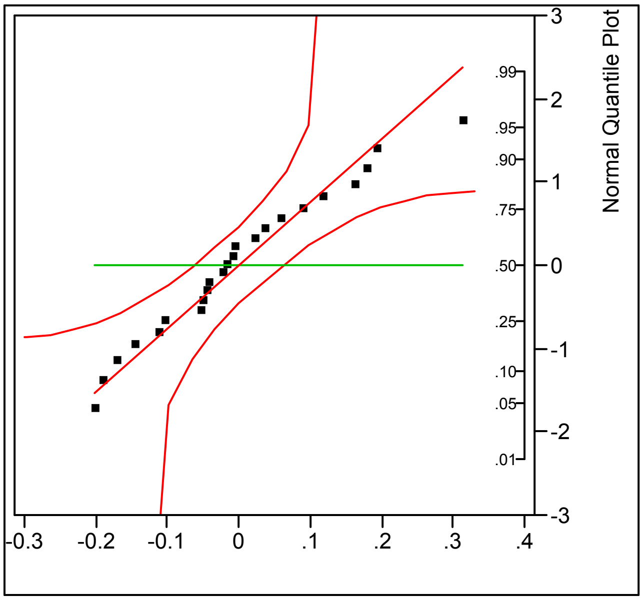


Figure K9-3 Normal Probability Plot of Residuals for the Regression Model

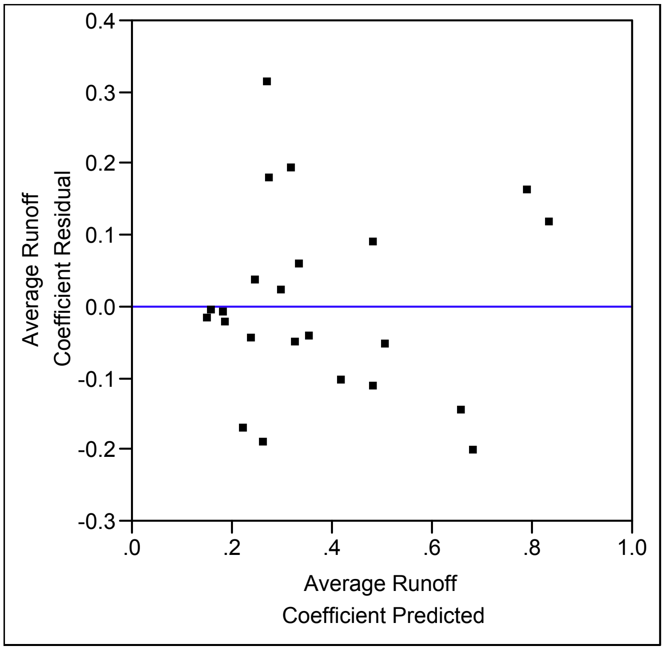


Figure K9-4 Residuals Against Predicted Values of the Response Variable

K9.2.4 Step 4. Use the Selected Regression Model to Predict the Response Variable for Specified Values of the Explanatory Variables

Once an acceptable regression model is developed, the interest is to use the model to predict the response variable for specified values of the explanatory variables and to assess the standard deviation of the response variable at the specified explanatory variables. The predicted value and the standard deviation are then used to calculate a *prediction interval* on the response variable with a specified confidence. A prediction interval with a confidence of $(1-\alpha) \times 100$ percent confidence defines an interval that will contain the response variable for given explanatory variables $(1-\alpha) \times 100$ percent of the time.

The predicted value of the response variable, $\hat{y}_x$, for a given vector of *x* values is calculated using the regression equation in which the estimated regression coefficients are used. Thus, the following equation, referred to in this appendix as Equation (2), is generated:

$$\hat{y}_x = b_0 + b_1 x_1 + b_2 x_2 + \ldots + b_n x_n$$

Because the regression equation is only an empirical relationship, the use of the equation to predict the response variable is valid only within the range of explanatory variables in the sample data. Caution should be exercised in making predictions of the response variable beyond the range of sample data (i.e., extrapolating results beyond the range of observations).

Statistical software packages provide options to calculate and save the predicted values, standard deviations, and confidence intervals of y_x for different sets of values(x_1, x_2, …, x_n).

The standard deviation, $s(y_x)$ of y_x, provided in statistical software may be considered an exact estimate because it accounts for all uncertainties. However, a reasonable approximation to the estimate of $s(y_x)$, which is relatively simple to calculate, is given by Equation (3):

$$s(y_x) \approx \text{RMSE} \times \sqrt{1 + \frac{1}{n}}$$

In this equation, n is the sample size and RMSE is (as previously defined) the root mean square error of the regression equation.

For a large sample size, $s(y_x)$ approaches RMSE and the probability distribution of y_x approaches the normal distribution.

A useful measure of the reliability of the regression equation to predict the response variable is the RMSE. If different regression equations are being considered for a response variable expressed on the same scale, one can compare the reliability of these equations in terms of their RMSE. An equation with lower RMSE should be preferred.

Results of Step 4 for Example K9-1

Suppose that one wants to predict the runoff coefficient at a new site that has the following values of the explanatory variables:

Dry density = 110 lb/ft^3, infiltration rate = 2.5 inches/hour, and hydraulic residence time = 8 minutes.

Using Equation (1), the runoff coefficient is calculated to be 0.224. The RMSE for the regression equation is 0.14. Therefore, an approximate estimate of the standard deviation of the runoff coefficient at this site is 0.14 × square root of (1 + 1/23) = 0.143, using Equation (3). Assuming normal distribution, the true runoff coefficient at this site would be within the interval (0.224 ± 0.143) about 68 percent of the time.

K9.3 Use of Regression Analysis to Predict Effluent Concentration

Regression analysis may be used to compare the performance of different BMPs in a pilot study based on predicted effluent quality. The influent quality is likely to be variable at the individual BMP sites and the effluent quality for many constituents depends on the influent quality. In this case, the effluent quality should be normalized with regard to the influent quality before comparing across different BMPs. The steps described in the previous section may be used to develop a regression equation to predict effluent event mean concentration (EMC) as a function of influent EMC. A reference influent EMC is defined and used to predict the effluent EMC using the regression equation at each BMP site. Procedures described in Appendix K6 can be used to test the hypothesis that the mean effluent EMC is the same at two different BMP sites.

Such an approach was used, for example, in the Caltrans BMP Retrofit Pilot Program[17]. Care should be taken to ensure that the key assumptions of a linear regression model, described in Step 3, are satisfied and the RMSE of the regression equation is small enough so that the predicted range of effluent concentration for a given BMP is not too wide. When the RMSE is large, important differences between BMPs may be masked by the uncertainty in the predicted effluent concentrations; that is, the ranges of predicted effluent concentrations at different BMPs may overlap.

[17] California Department of Transportation. BMP Retrofit Pilot Program. Final Report. January 2004.

Appendix K10 How to Evaluate Time Trends in BMP Monitoring Data

K10.1 Purpose and Organization

The purpose of this appendix is to present statistical methods to evaluate whether BMP data show significant trends over time. The methods can address a typical question of interest in BMP studies; namely, is the effectiveness of a particular BMP expressed (e.g., in terms of percent removal of a pollutant) changing over time? The focus of the methods is on evaluating the presence of a *monotonic* trend in a time series of sample data. For evaluating other temporal trends, such as seasonal effects, the methods of hypothesis testing described in Appendices K6 and K8 should be used.

For BMP studies, data would be colleted during each storm event that meets certain threshold conditions in each of several monitoring years. Interest will be in evaluating two types of time trends:

1. Intra-year trend

   Does a monitoring parameter of interest (e.g., the concentration of a certain pollutant) show a systematic trend over different storm events in a given year? For example, one would like to assess whether the effects of the storms on pollutant concentration are different during the initial storms in a wet season, due to flushing of materials accumulated prior to the start of a wet season.

2. Inter-year trend

   Does a monitoring parameter show a systematic trend over different monitoring years? For example, one would like to assess whether the BMP effectiveness is decreasing over years.

This appendix presents methods to evaluate both types of trends. A common example will be used to illustrate the application of these methods to BMP studies. The data for this example are presented first. Methods for the two types of trend analysis are described next and illustrated using the example data.

Example K10-1

Consider a BMP study that used the influent-effluent monitoring approach to collect data on TSS loads in the influent and effluent at a BMP structure over a period of four years. The influent and effluent TSS loads for each sampling event were used to calculate the percent reduction in the TSS load. Table K10.1 shows a summary of the data on the percent reduction in TSS load for each storm event of each monitoring year. The questions of interest for this BMP study are:

- Does the percent TSS load reduction show a systematic variation over different storm events within each monitoring year? For example, is the percent TSS load reduction different for the initial storm events of the rainy season? If the initial events consistently show a lower percent reduction in a pollutant, this might suggest the need for a supplementary BMP maintenance practice during the start of a rainy season that would increase the effectiveness of the program.

- Does the percent TSS load reduction show a trend over the monitoring years? Is the BMP effectiveness changing over time? If the analysis shows a decreasing trend in BMP effectiveness, supplementary BMP actions might be necessary.

Table K10.1 Percent Reduction in TSS Load Data for Example K10-1

Event ID	Percent Reduction in TSS Load by Event			
	Year 1	**Year 2**	**Year 3**	**Year 4**
1	27.5	20.1	9.8	13.7
2	25.4	21.4	17	8.6
3	21.2	21.7	12.7	10
4	24.7	17.8	18.8	10.2
5	28.2	17.4	14.2	8.8
6	20.9	24.9	13.8	9.3
7	29	28.9	11.7	6.4
8	22.7	19.4	14.6	9.4
9		25.1	12.3	10.9
10		22.8		7.9
11		12.4		6.7
12				10.7
Annual Percent Reduction in TSS Load	25.5	20.4	14.1	8.6

K10.2 Evaluation of Intra-Year Trends

Both a graphical method and a formal statistical test (Mann-Kendall test) are recommended for the evaluation of intra-year trends.

K10.2.1 Graphical Method

A time series plot is prepared that plots the monitoring parameter as a function of the time of the sampling event for each monitoring year. Such plots can be prepared using Excel graph functions. The time pattern within each monitoring year is examined visually to assess whether there are any consistent monotonic (upward or downward) trends. If the plot does not show a monotonic trend, but does show two or more distinctly different time periods (e.g., the two halves of a wet season) with regard to observed values of the monitoring parameter, the methods of hypothesis testing described in Appendix K6 or K8 should be used to evaluate whether the differences between the time periods are statistically significant.

K10.2.2 Mann-Kendall Test

The Mann-Kendall (M-K) test is described in detail in Gilbert (1987)[18] and also in the USEPA Guidance Document (2006)[19]. It is used to evaluate monotonic trends. This is a nonparametric test that does not assume any particular probability distribution for the sample data. Also, nondetect values can be incorporated by assigning them a common value that is smaller than the lowest detected value. This approach is valid because the M-K test uses only the relative magnitudes of the data rather than their actual values. The recommended minimum sample size (i.e., the annual number of storm events for the present analysis) for the M-K test is eight. Statistical software packages, such as JMP, do not include the M-K test. However, the following programs/software are available to run the M-K test:

- The FORTRAN program code provided in Gilbert's book
- Visual Sample Plan (version 4) software, developed by the U.S. Department of Energy, provides a module to run the M-K test[20]
- Kendall.exe (a DOS-executable), provided by the U.S. Geological Survey[21]

[18] Gilbert, Richard O. 1987. *Statistical Methods for Environmental Pollution Monitoring.* Van Nostrand Reinhold, New York.
[19] USEPA. 2006. *Data Quality Assessment: Statistical Methods for Practitioners*. EPA QA/G-9S. Office of Environmental Information, Washington, DC.
[20] Hassig, N.L., R.O. Gilbert, J.E. Wilson, B.A. Pulsipher, and L.L. Nuffer. 2005. *Visual Sample Plan 4.0 User's Guide.* PNHL-15247. Pacific Northwest National Laboratory, Richland, Washington, prepared for the U.S. Department of Energy. http://dqo.pnl.gov/VSP.

Also, one can set up an Excel spreadsheet to calculate the *S* statistics (described below) and determine the M-K test result.

The M-K test follows the standard principles of hypothesis testing that were described in Appendix K6. The null hypothesis is defined to be one of no trend. The alternative hypothesis could be either two-tailed (i.e., there is an upward or downward trend) or one-tailed (i.e., there is a trend only in one direction, either upward or downward). The data are listed in the time order and the signs (positive or negative) of differences between a measured concentration versus all other measured concentrations prior to it, are found. The signs are used to calculate a statistics denoted by *S*, which is the number of positive differences minus the number of negative differences. If *S* is a large positive number, measurements taken later in time tend to be larger than those taken earlier (i.e., there is an increasing trend). Conversely, if *S* is a large negative number, measurements taken later in time tend to be smaller (i.e., there is a decreasing trend).

The probability of getting a statistics greater than the absolute value of *S* by chance alone is calculated. This is the significance probability, *p*, of the test. If *p* is less than a specified threshold (typically 0.05), this is taken as evidence of a significant monotonic trend. Note that for Caltrans studies, the 90 percent confidence level should be used. The sign of the statistics *S* and the time series plot will inform the user whether there is an increasing or decreasing trend. If *p* is greater than, or equal to, the specified threshold, one concludes that the data do not provide sufficient evidence of a monotonic trend. The *p*-value can be determined by using Table A-12b of USEPA (2006), in which the *p*-value depends on sample size, *n*, and the Mann-Kendall statistic, *S*.

Results of Intra-Year Trend Analysis for Example K10-1

Figure K10-1 shows a time series plot of the data listed in Table K10.1. The figure reveals no particular trend in the percent reduction in TSS loads for any of the four monitoring years. The M-K test was applied using an Excel set-up. The results are shown in Table K10.2. The significance probabilities, *p*, are 0.45, 0.44, 0.46, and 0.27 for Years 1, 2, 3, and 4, respectively, which support the conclusion of no trend drawn from the time series plot.

[21] U.S. Geological Survey. 2005. “Computer Program for the Kendall Family of Trend Tests.” Scientific Investigations Report 2005-5275. http://pubs.usgs.gov/sir/2005/5275.

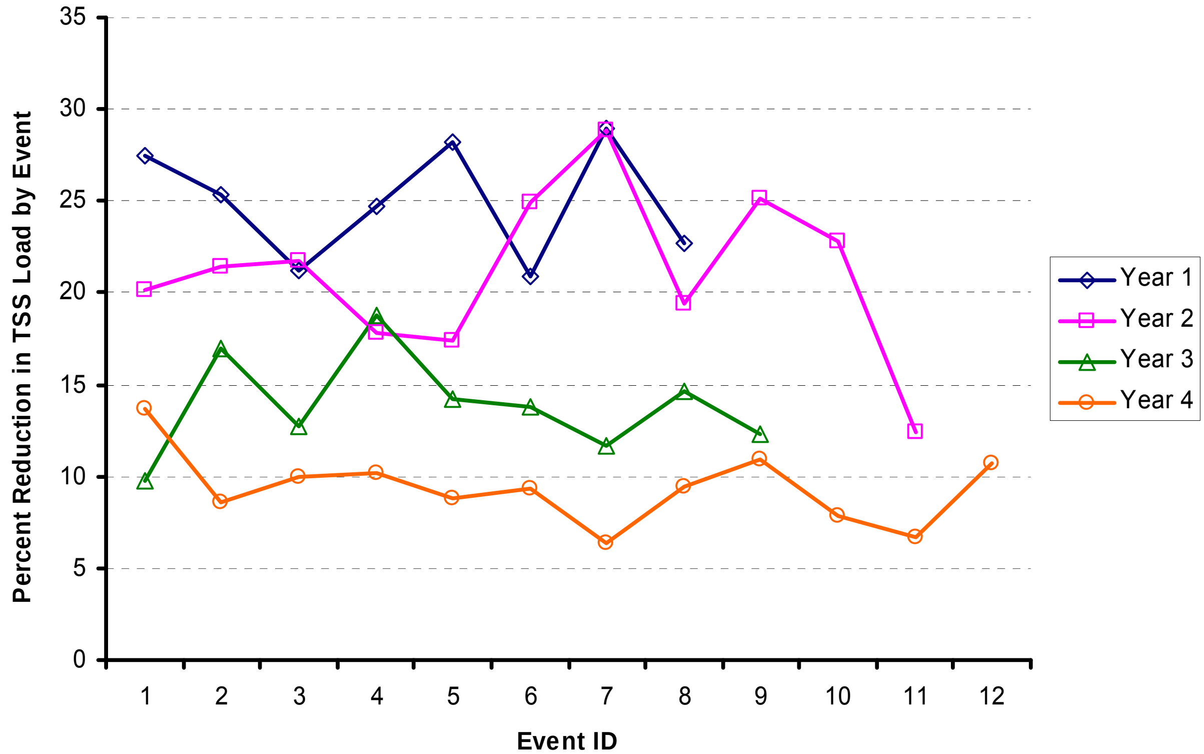


Figure K10-1 Time Series Plot of Percent Reduction in TSS Loads for Example K10-1

Table K10.2 Intra-Year Mann-Kendall Test Results for Example K10-1

Year	Number of Sampling Periods	Number of Positive Differences	Number of Negative Differences	*S*	M-K Test *p*-value	Trend Result
Year 1	8	13	15	-2	0.452	No Trend
Year 2	11	29	26	3	0.44	No Trend
Year 3	9	17	19	-2	0.46	No Trend
Year 4	12	28	38	-10	0.273	No Trend

K10.3 Evaluation of Inter-Year Trends

The question of interest for this analysis is whether the BMP monitoring parameters show any trends over different monitoring years. Again, both a graphical method and a formal statistical test (M-K test) are recommended for the evaluation of inter-year trends.

K10.3.1 Graphical Method

A time series plot is prepared that plots the monitoring parameter versus the monitoring year. Excel graphing functions can be used to prepare such plots. The time pattern over the monitoring years is examined visually to assess whether the plot exhibits a monotonic (increasing or decreasing) trend over the monitoring period. If there is no trend, the data points will plot randomly on either side of the overall mean value. If a trend exists, the data points will show a systematic pattern of increasing or decreasing values.

K10.3.2 Mann-Kendall Test

This test is applied as described in the previous section. As was noted previously, the recommended minimum sample size for the M-K test is eight. However, the number of monitoring years for typical BMP studies is only two to four years. If the sample size is less than four, the M-K test should not be applied. If the sample size is between four and seven, the M-K test may be performed, but its results should be used with caution and always supported by a visual inspection of the time series plot.

As noted previously, the key result of the M-K test is the significance probability, p. If p is less than a specified threshold (typically 0.05), this is taken as evidence of a significant trend. If p is greater than or equal to the threshold, one concludes that the data do not provide sufficient evidence of a trend. Note that for Caltrans studies, the 90 percent confidence level should be used.

Results of Inter-Year Trend Analysis for Example K10-1

Figure K10-2 shows a time series plot of the annual percent reduction in TSS load. The plot suggests that there is a decreasing trend in the percent reduction in the TSS load over the four years of the BMP monitoring program. This result might be an indication of decreasing BMP performance over the four monitoring years. The M-K test was performed next. The significance probability, p, for the test is 0.042, suggesting the presence of a significant, decreasing trend. Because the sample size is only four, the results of the M-K test should be used with caution, primarily to reinforce the conclusion drawn from the time series plot.

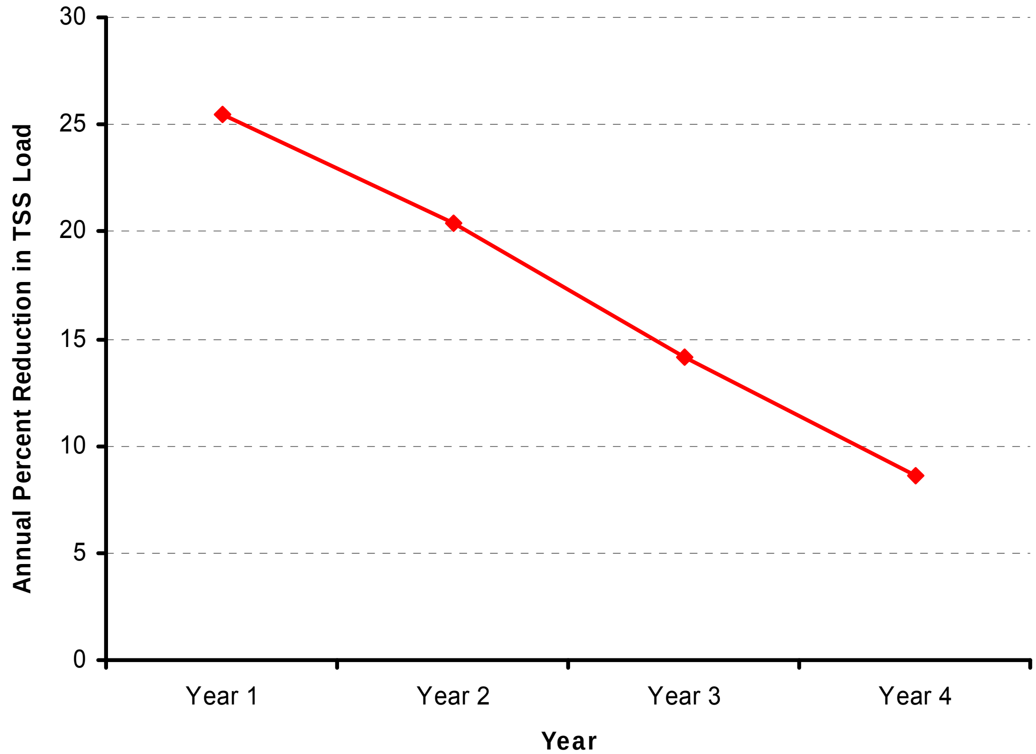


Figure K10-2 Time Series Plot of Annual Percent Reduction in TSS Loads for Example K10-1

Table K10.3 Inter-Year Mann-Kendall Test Results for Example K10-1

Number of Sampling Periods	Number of Positive Differences	Number of Negative Differences	*S*	M-K Test *p*-value	Trend Result
4	0	6	-6	0.042	Downward

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